Energy in the United States: 1635-2000

Introduction

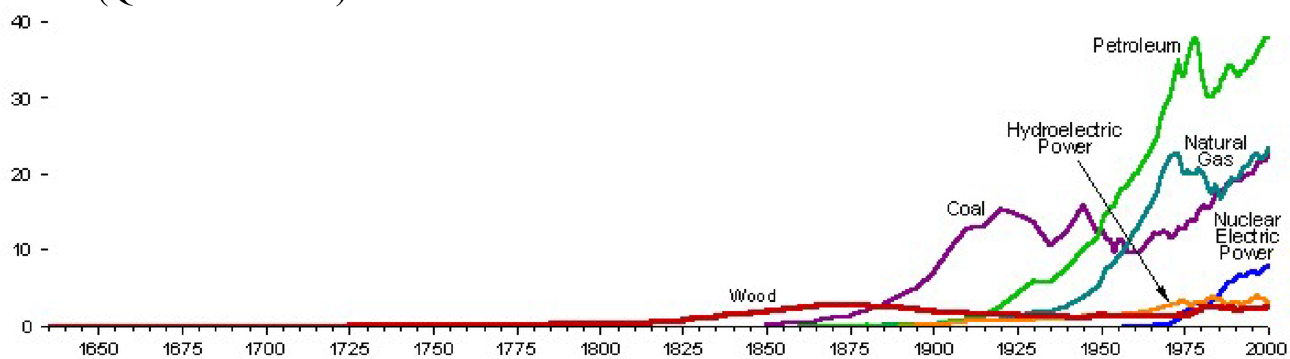
Energy is essential to life. Living creatures draw on energy flowing through the environment and convert it to forms they can use. The most fundamental energy flow for living creatures is the energy of sunlight, and the most important conversion is the act of biological primary production, in which plants and sea-dwelling phytoplankton convert sunlight into biomass by photosynthesis. The Earth's web of life, including human beings, rests on this foundation.

Over millennia, humans have found ways to extend and expand their energy harvest, first by harnessing draft animals and later by inventing machines to tap the power of wind and water. Industrialization, the watershed social and economic development of the modern world, was enabled by the widespread and intensive use of fossil fuels. This development freed human society from the limitations of natural energy flows by unlocking the Earth's vast stores of coal, oil, and natural gas. Tapping these ancient, concentrated deposits of solar energy enormously multiplied the rate at which energy could be poured into the human economy.

The result was one of the most profound social transformations in history. The new river of energy wrought astonishing changes and did so with unprecedented speed. The energy transformations experienced by traditional societies--from human labor alone to animal muscle power and later windmills and watermills--were very slow, and their consequences were equally slow to take effect. In contrast, industrialization and its associated socioeconomic changes took place in the space of a few generations.

The history of energy use in the United States reflects these general themes. Wood energy, for example, has been a significant part of the U.S. energy mix since colonial times (Figure 1). In fact, fuelwood was overwhelmingly the dominant energy source from the founding of the earliest colonies until late in the last century. But thereafter, the modern era is notable for the accelerated appearance of new sources of energy, in contrast to the imperceptible pace of change in earlier times. Coal ended the long dominance of fuelwood in the United States about 1885, only itself to be surpassed in 1951 by petroleum and then by natural gas a few years later. Hydroelectric power and nuclear electric power appeared about 1890 and 1957, respectively. Solar photovoltaic, advanced solar thermal, and geothermal technologies represent further recent developments in energy sources. The most striking of these entrances, however, is that of petroleum and natural gas. The curves depicting their consumption remain shallow for several decades following the success of Edwin Drake's drilling rig in 1859, but begin to rise more steeply in the 1920s. Then, interrupted only by the Depression, the curves climb at increasingly alpine angles until 1973. Annual consumption of petroleum and natural gas exceeded that of coal in 1947 and then quadrupled in a single generation. Neither before nor since has any source of energy become so dominant so quickly.

Figure 1. Energy Consumption by Source, 1635-2000
(Quadrillion Btu)



As for the social, economic, and ecological consequences of evolving energy sources, they are too deep and numerous to do more than give suggestive examples. One of the most significant is the shift between muscle- and machine power. Horses, mules, and other draft animals were invaluable prime movers well into the first half of the 20th century, and despite increasing reliance on fossil fuels and the engines they powered, the number of draft animals in the United States continued to rise until about 1920. As late as 1870, draft animals accounted for more than half of the total horsepower of all prime movers. Their displacement by fossil-fuel engines meant, eventually, the disappearance from city and farm alike of millions of animals, along with the vast stables that housed the city-based animals, the mountains of dung they left on city streets, and many of the English sparrows that fed on the grain therein.

As fossil fuels and the machines that ran on them proliferated, the nature of work itself was transformed along with the fundamental social, political, and geopolitical circumstances of the Nation. In the middle of the 19th century, most Americans lived in the countryside and worked on farms. The country ran mainly on wood fuel and was relatively unimportant in global affairs. A hundred years later, after the Nation had become the world's largest producer and consumer of fossil fuels, most Americans were city-dwellers and only a relative handful were agricultural workers. The United States had roughly tripled its per-capita consumption of energy and become a global superpower.

Although coal, oil, and natural gas are the world's most important energy sources, their dominance does not extend to all corners of the globe. In most places and times diversity and evolution in energy supplies has been the rule. In many areas muscle power and biomass energy remain indispensable or even primary. The shifting emphasis over time is clear not only in the long sweep of history but also in the short term, especially in the industrialized world. Electricity, for example, was essentially unavailable until the 1880s; now it is ubiquitous. And in the span of a few decades nuclear electric power in the United States was born, peaked, and began to decline in its contribution to total energy production.

No doubt we have not seen the end of evolution in energy sources. The paragraphs that follow briefly discuss the major energy sources now in use in the United States, including a bit of history, trends, and snapshots of consumption and production patterns as of 2000. The story they tell is one of diversity and transformation, driven by chance, the play of economic forces, and human ingenuity. Whatever energy future awaits us, that part of the story seems unlikely to change.

Total Energy

The United States has always been a resource-rich nation, but in 1776, the year the Nation declared its independence from Great Britain, nearly all energy was still supplied by muscle power and fuelwood. America's vast deposits of coal and petroleum lay untapped and mostly undiscovered, although small amounts of coal were used to make coke, vital for casting the cannon that helped win the war. Mills made use of waterpower, and of course the wind enabled transport by ship.

Fuelwood use continued to expand in parallel with the Nation's economic growth, but chronic shortages of energy in general encouraged the search for other sources. During the first 30 years or so of the 19th century, coal began to be used in blast furnaces and in making coal-gas for illumination. Natural gas also found limited application in lighting during the period. Even electricity sought a niche; for example, experiments were conducted with battery-powered electric trains in the 1840s and 1850s. Still, muscle power remained an important source of energy for decades. Although a number of mechanical innovations appeared, including the cotton gin and the mechanical reaper, they had the effect of multiplying the productivity of human and animal muscle power rather than spurring the development of machine power. It was not until well after mid-century that the total work output from all types of engines exceeded that of work animals.

The westward expansion helped change that. As railroads drove west to the plains and the mountains, they left behind the fuelwood so abundant along the eastern seaboard. Coal became more attractive, both because deposits were often found near the new railroad rights of way and because its higher energy content increased the range and load of steam trains. Demand for coal also rose because the railroads were laying thousands of miles of new track and the metals industry needed an economical source of coke to make iron and steel for the rails and spikes. The transportation and industrial sectors in general began to grow rapidly during the latter half of the century, and coal helped fuel their growth.

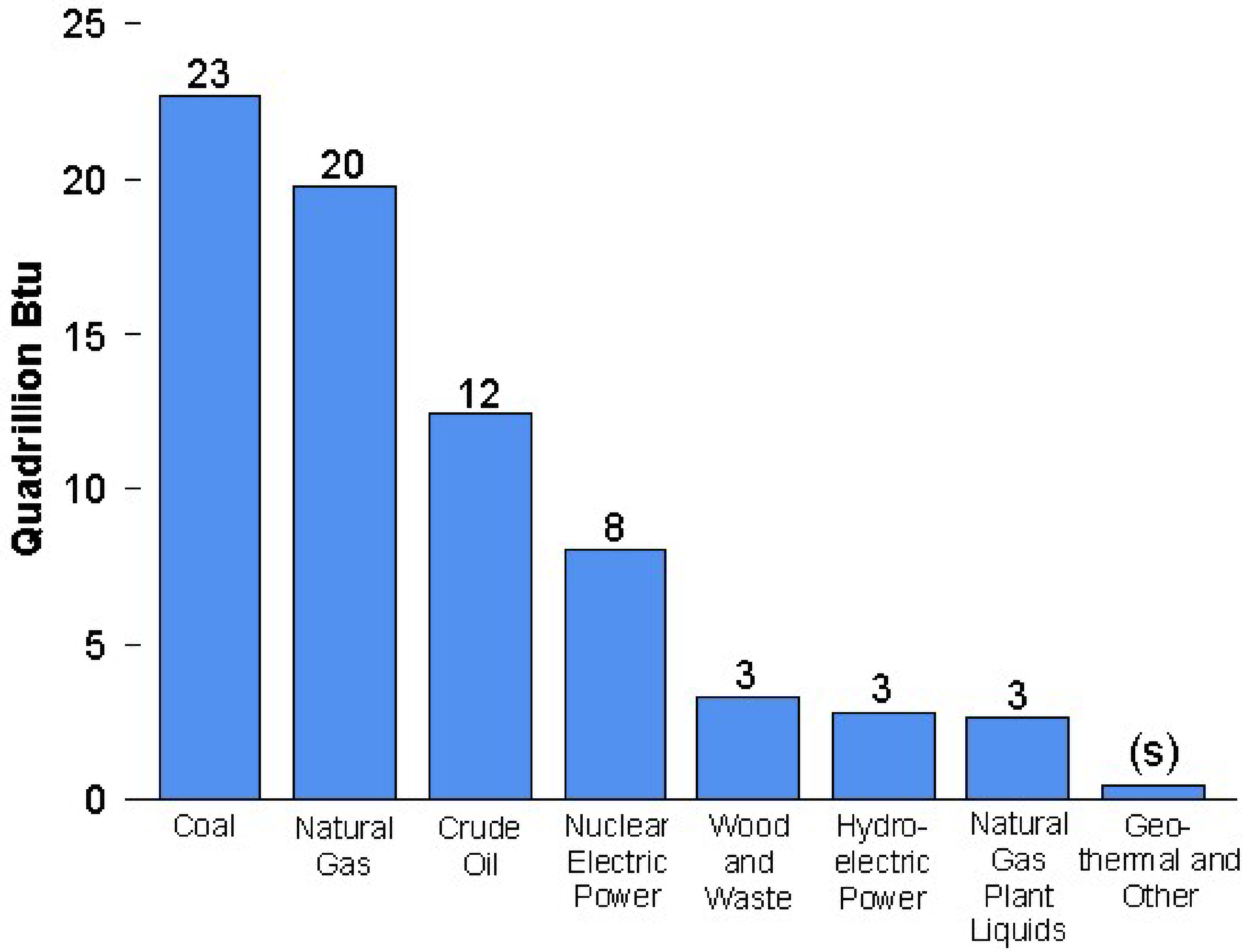
Petroleum got its start as an illuminant and ingredient in patent medicines and did not catch on as a fuel for some time. At the end of World War I, coal still accounted for about 75 percent of U.S. total energy use. About the same time, the horse and mule population reached 26 million and then went into permanent decline. The beginning of the transition from muscle power was over.

America's appetite for energy as it industrialized was prodigious, roughly quadrupling between 1880 and 1918. Coal fed much of this growth, while electricity expanded in applications and total use alike. Petroleum got major boosts with the discovery of Texas's vast Spindletop Oil Field in 1901 and with the advent of mass-produced automobiles, several million of which had been built by 1918.

In the years after World War II, "Old King Coal" relinquished its place as the premier fuel in the United States. The railroads lost business to trucks that ran on gasoline and diesel fuel, and also began switching to diesel locomotives themselves. Labor troubles and safety standards drove up coal production costs. The declining demand for natural gas as an illuminant forced that industry to look for other markets, and because heating applications had obvious potential, natural gas replaced coal in many household ranges and furnaces. The coal industry survived, however, mainly because nationwide electrification created new demand for coal among electric utilities despite regional competition from hydroelectric and petroleum-fired generation.

Most energy produced today in the United States, as in the rest of the industrialized world, comes from fossil fuels--coal, natural gas, crude oil, and natural gas plant liquids (Figure 2). Although U.S. energy production takes many forms, fossil fuels together far exceed all other sources of energy. In 2000 they accounted for 80 percent of total energy production and were valued at an estimated $148 billion (nominal dollars).

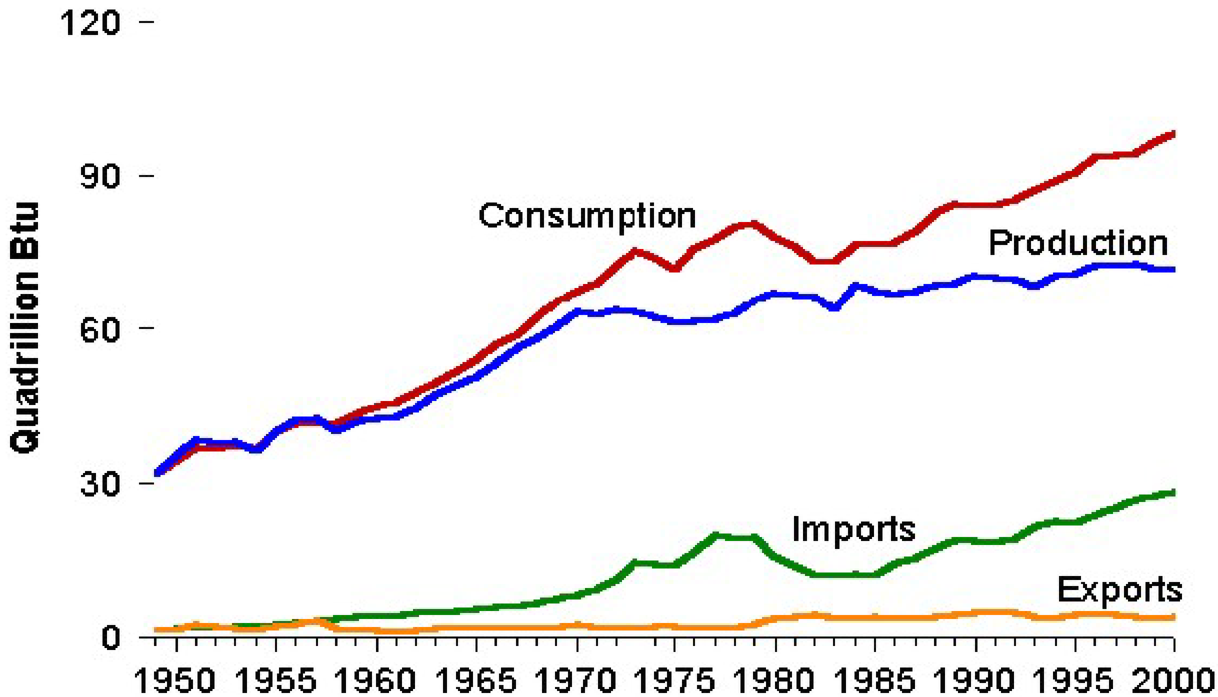
Figure 2. Energy Production by Source for 2000



(s)=less than 0.5 quadrillion Btu

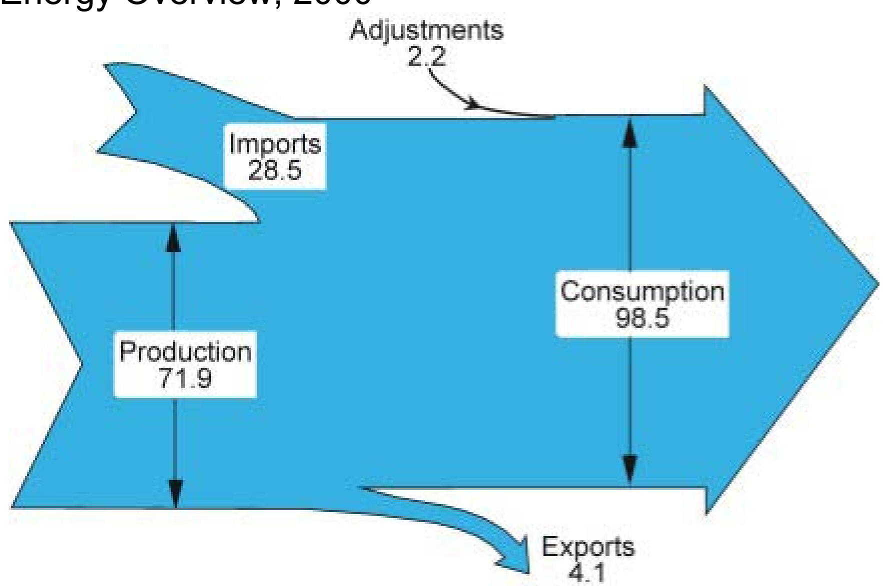
For much of its history, the United States was mostly self-sufficient in energy, although small amounts of coal were imported from Britain in colonial times. Through the late 1950s, production and consumption of energy were nearly in balance. Over the following decade, however, consumption slightly outpaced domestic production and by the early 1970s a more significant gap had developed (Figure 3).

Figure 3. Energy Overview



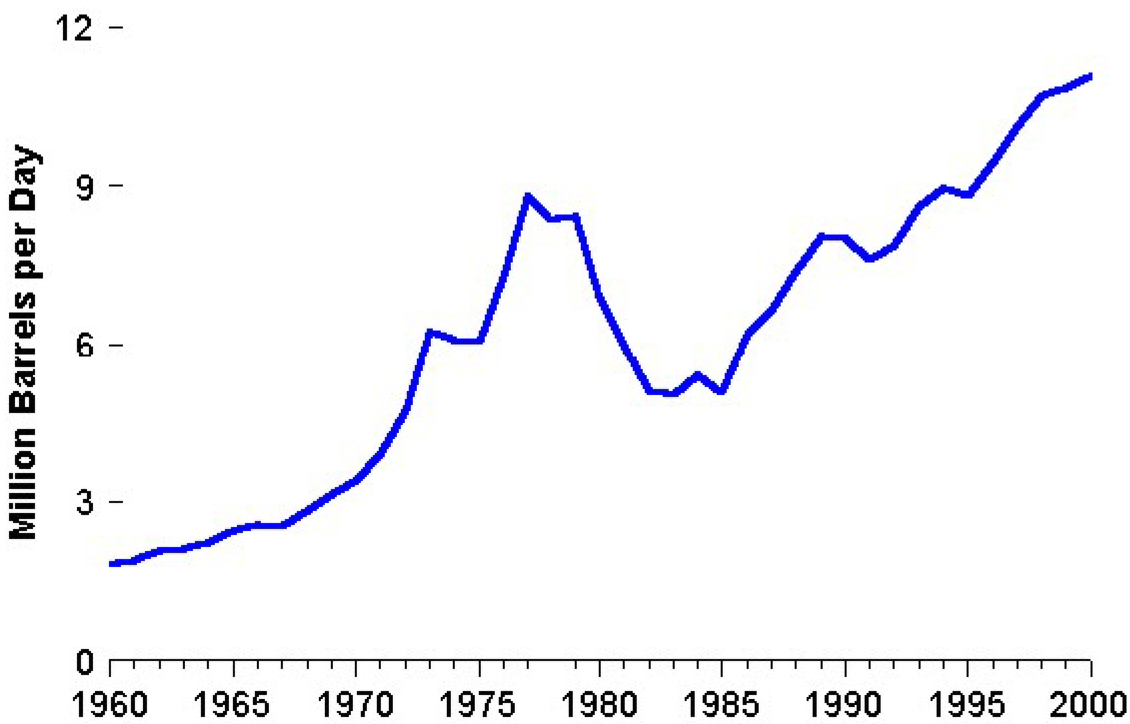
In 2000 the United States produced just under 72 quadrillion British thermal units (Btu) of energy and exported roughly 4 quadrillion Btu. Consumption totaled about 98 quadrillion Btu, requiring imports of almost 29 quadrillion Btu (Figure 4), 19 times the 1949 level.

Figure 4. Energy Overview, 2000



This appetite for imported energy is driven by petroleum consumption. U.S. petroleum imports in 1973 totaled 6.3 million barrels per day (3.2 million barrels per day of crude oil and 3.0 million barrels per day of petroleum products). In October 1973, however, the Arab members of the Organization of Petroleum Exporting Countries (OPEC) embargoed the sale of oil to the United States, prices rose sharply, and petroleum imports fell for two years (Figure 5). They increased again until the price of crude oil rose dramatically (roughly 1979 through 1981) and suppressed imports. The rising-import trend resumed by 1986 and, except for slight dips in 1990, 1991, and 1995, has continued ever since. In 2000 U.S. petroleum imports reached an annual record level of 11 million barrels per day.

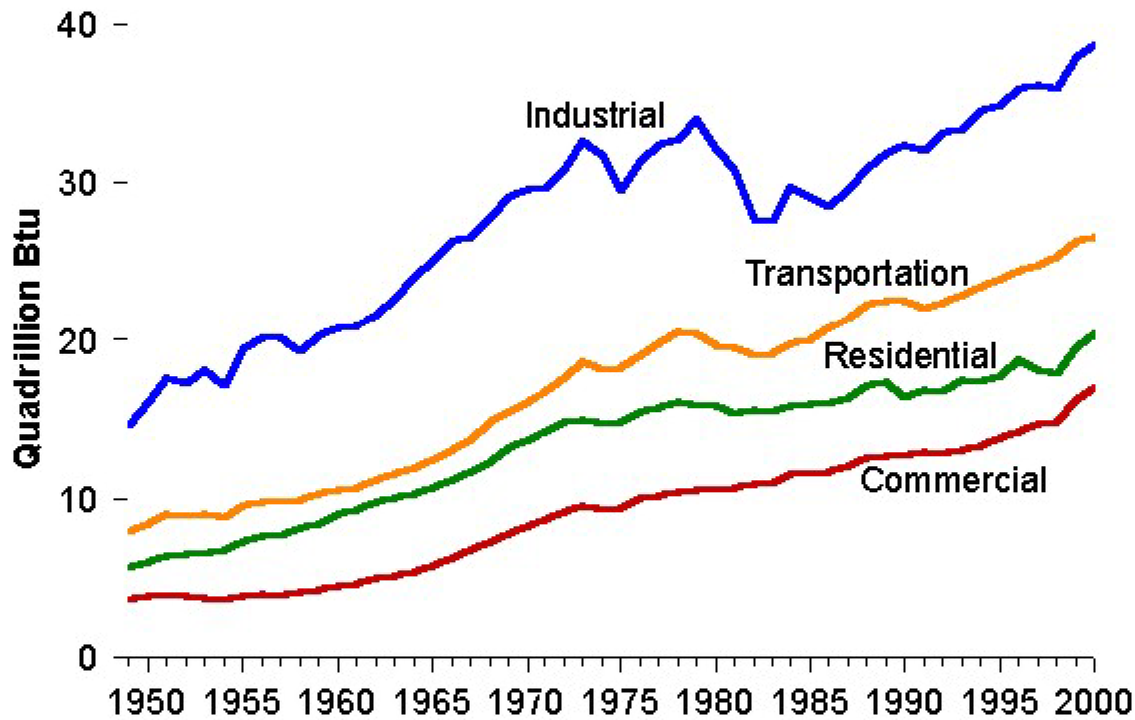
Figure 5. Petroleum Imports, 1960-2000



The efficiency with which Americans use energy has improved over the years. One such measure is the amount of energy consumed to produce a (constant) dollar's worth of gross domestic product (GDP). By that yardstick, efficiency improved 49 percent between 1949 and 2000, as the amount of energy required to generate a dollar of output (chained 1996 dollars) fell from 20.6 thousand Btu to 10.6 thousand Btu. Nevertheless, a growing population and economy drove total energy use up. As the U.S. population expanded from 149 million people in 1949 to 281 million in 2000 (an increase of 89 percent), total energy consumption grew from 32 quadrillion Btu to 98 quadrillion Btu (up 208 percent). Per-capita energy consumption rose 63 percent, from 215 million Btu in 1949 to 350 million Btu in 2000.

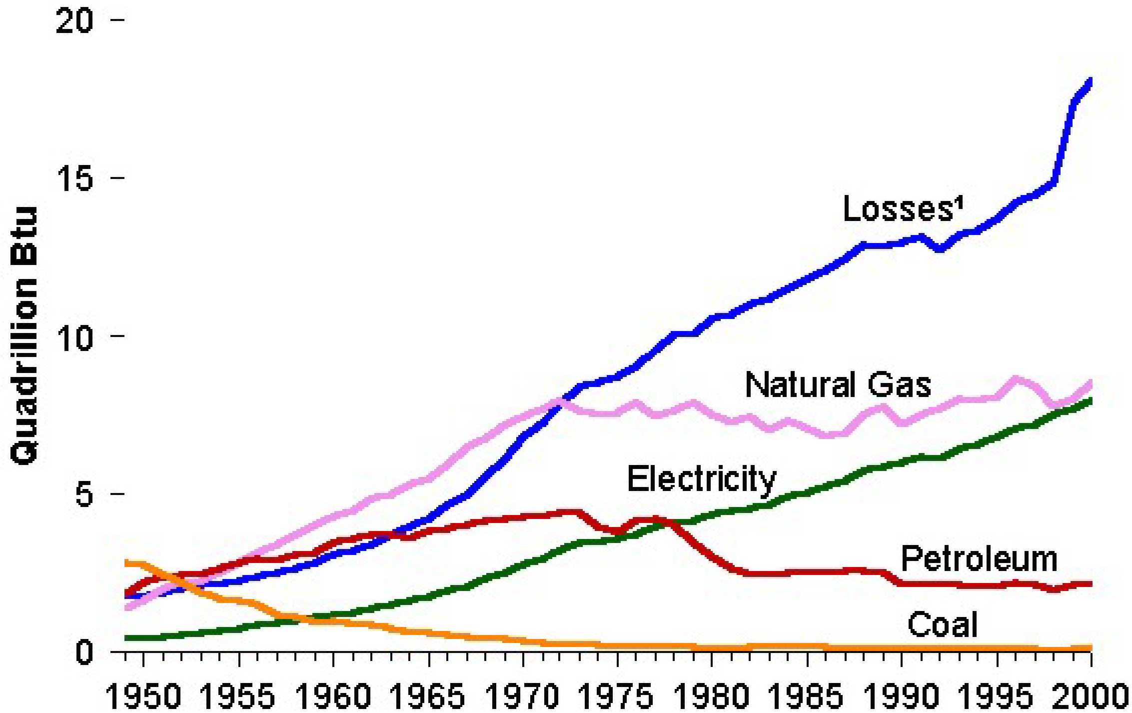
Energy plays a central role in the operation of the industrialized U.S. economy, and energy spending is commensurately large. In recent years, American consumers have spent over half a trillion dollars a year on energy. That energy is consumed in four broad sectors: residential, commercial, industrial, and transportation. Industry is historically the largest consuming sector of the economy. In contrast to the relatively smooth trends in the other sectors, industrial energy use has fluctuated sharply (Figure 6).

Figure 6. Energy Consumption by End Use



Sectoral energy sources have changed dramatically over time. In the residential and commercial sectors, for example, coal was the leading source as late as 1951 but then disappeared rapidly (Figure 7). Petroleum usage grew slowly to its peak in 1972 and then subsided. Natural gas became an important resource, growing strongly until 1972, when its growth essentially stalled. Electricity, only an incidental source in 1949, expanded in almost every year since then, as did the energy losses associated with producing and distributing the electricity. (See "Electricity" section below for an explanation of these losses.)

Figure 7. Residential and Commercial Energy Consumption



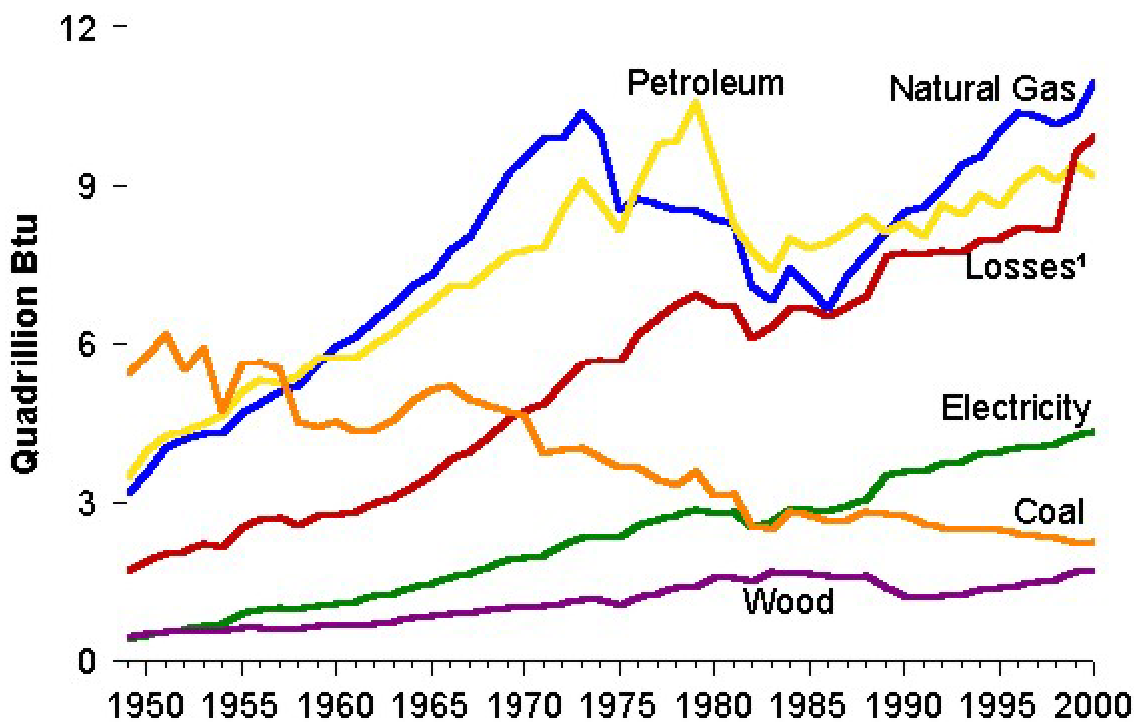
[1]Energy lost during generation, transmission, and distribution of electricity

The expansion of electricity use reflects the increased electrification of U.S. households, which typically rely on a wide variety of electrical appliances and systems. In 1997, 99 percent of U.S. households had a color television and 47 percent had central air conditioning. Eighty-five percent of all households had one refrigerator; the remaining 15 percent had two or more. New products continued to penetrate the market; for example, in 1978 only 8 percent of U.S. households had a microwave oven, but by 1997 microwaves could be found in 83 percent. The Energy Information Administration (EIA) first collected household survey data on personal computers in 1990, when 16 percent of households owned one or more. By 1997 that share had more than doubled to 35 percent.

U.S. home heating also underwent a big change. Over a third of all U.S. housing units were warmed by coal in 1950, but by 1999 that share was only 0.2 percent. Distillate fuel oil lost more than half its share of the home-heating market during the same period, falling from 22 percent to 10 percent. Natural gas and electricity gained as home-heating sources: the share of natural gas rose from about a quarter of all homes to over half, while electricity's share shot up from only 0.6 percent in 1950 to 30 percent in 1999. In recent times, electricity and natural gas have been the most common sources of energy used by commercial buildings as well.

In the industrial sector, the consumption of both natural gas and petroleum rose steadily and in tandem until the oil embargo in 1973, after which their use fluctuated (Figure 8). Consumption of coal, once the leading source in the sector, shrank. Electricity and its associated losses grew steadily.

Figure 8. Industrial Energy Consumption

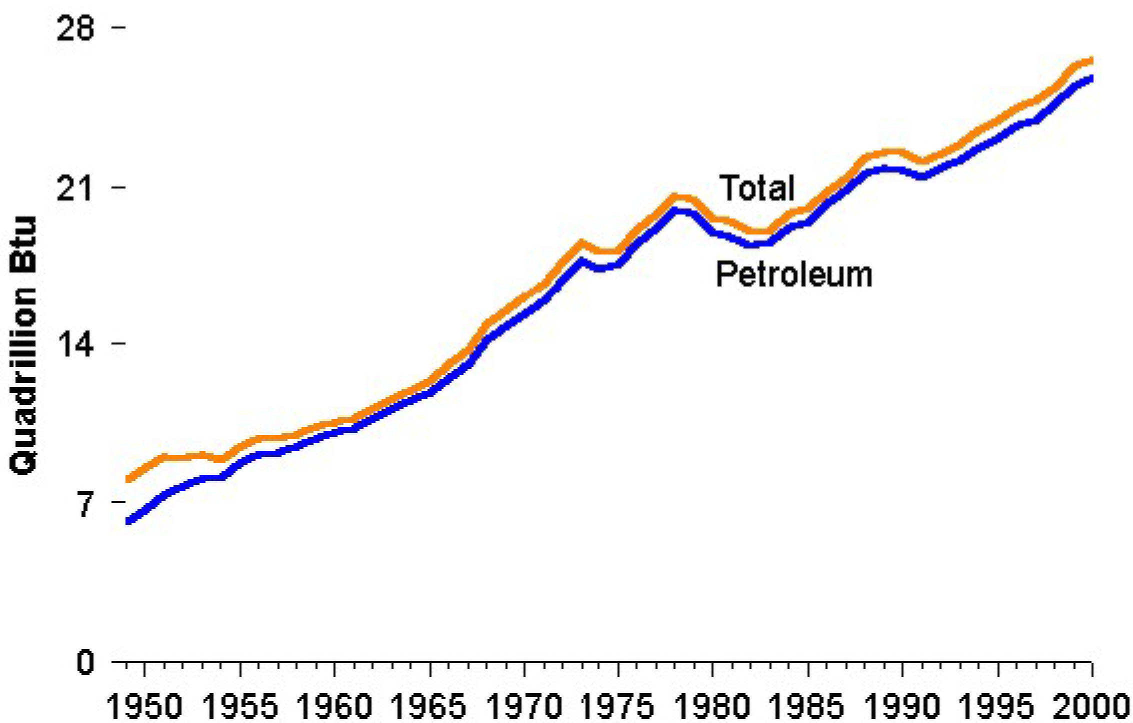


[1]Energy lost during generation, transmission, and distribution of electricity

About three-fifths of the energy consumed in the industrial sector is used for manufacturing. The remainder goes to mining, construction, agriculture, fisheries, and forestry. Within manufacturing, large consumers of energy are the petroleum and coal products, chemicals and allied products, paper and allied products, and primary metal industries. Natural gas is the most commonly consumed energy source in manufacturing. The predominant end-use activity is process heating, followed by machine drive and then facility heating, ventilation, and air conditioning combined. About 7 percent of all energy consumed in the United States is used for nonfuel purposes, such as asphalt and road oil for roofing products and road building and conditioning; liquefied petroleum gases for feedstocks at petrochemical plants; waxes for packaging, cosmetics, pharmaceuticals, inks, and adhesives; and still gas for chemical and rubber manufacture.

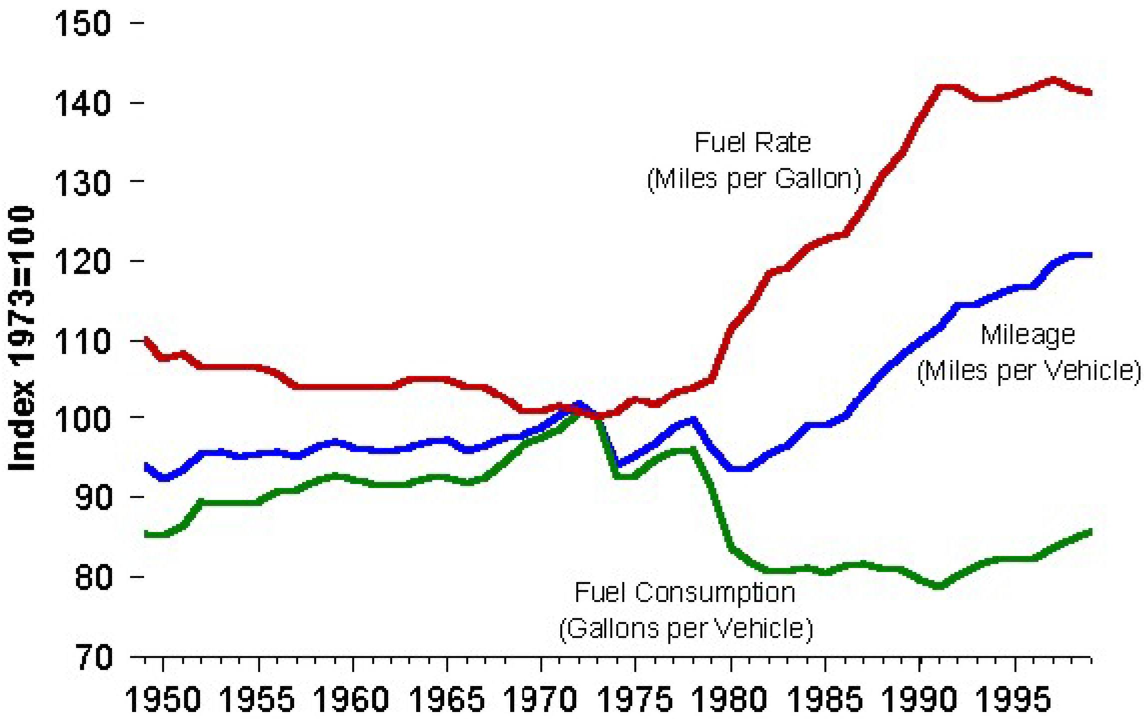
While variety and change in energy sources are the hallmarks of the industrial, residential, and commercial sectors, transportation has relied almost totally on petroleum since 1949 (Figure 9).

Figure 9. Transportation Energy Consumption



Compared with trends just prior to the oil embargo of 1973, fuel consumption per motor vehicle fell in the two decades that followed, miles traveled per vehicle generally fell until the early 1980s and then resumed a pattern of increase, and the fuel rate (i.e., miles per gallon) improved greatly before essentially leveling off in the 1990s (Figure 10).

Figure 10. Motor Vehicle Indicators



Petroleum

It is hard to imagine a world without petroleum, partly because humans have been using it since at least 3000 BCE. Mesopotamians of that era used "rock oil" in architectural adhesives, ship caulks, medicines, and roads. The Chinese of two millennia ago refined crude oil for use in lamps and in heating homes. Seventh-century Arab and Persian chemists discovered that petroleum's lighter elements could be mixed with quicklime to make "Greek fire," the napalm of its day. From these scattered uses, petroleum has come to occupy a central place in modern civilization. Today petroleum still finds applications in buildings, shipping, medicine, roads, and warfare. It is crucial to many industries, including chemicals and agriculture. Above all, it dominates the world energy scene.

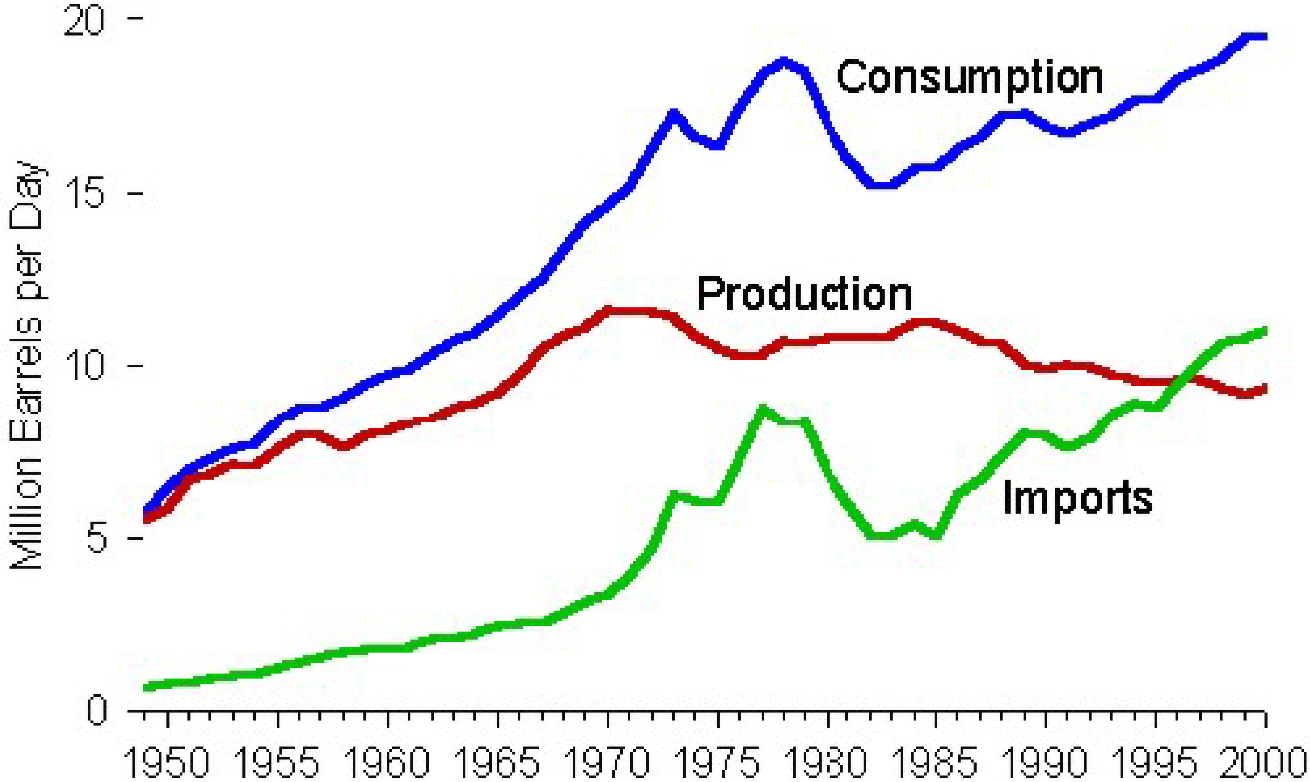
Petroleum was known to native peoples in the northeastern parts of the colonial United States, and was put to various uses by some tribes. A French military officer noted in 1750 that Indians living near Fort Duquesne (now the site of Pittsburgh) set fire to an oil-slicked creek as part of a religious ceremony. As settlement by Europeans proceeded, oil was discovered in many places in northwestern Pennsylvania and western New York--to the annoyance of many well-owners, who were usually drilling for salt brine.

In the mid-1800s, expanding uses for oil extracted from coal and shale began to hint at the value of rock oil and encouraged the search for readily accessible supplies. This impetus launched the modern petroleum age, which began in August 1859 at Oil Creek in northwestern Pennsylvania. The credit has traditionally gone to "Colonel" Edwin L. Drake, a railroad conductor on sick leave who was hired (and given his fictitious title) by the Pennsylvania Rock Oil Company. After months of effort and many setbacks, Drake's homemade drilling rig reached 70 feet, and the bit came up coated with oil. (Ironically, it was Sunday afternoon and Drake was off. And in fact his backers had already ordered him to stop, but the letter was delayed.)

"Great excitement ensued," according to the account in the 1883 edition of *Mineral Resources of the United States*. Drake's discovery ignited an oil boom, which was fed by strong demand for lighting fuel and lubricants. Over the next four decades the boom spread to Texas and California in the United States and to Romania, Baku (in Azerbaijan), Sumatra, Mexico, Trinidad, Iran, and Venezuela. Overproduction temporarily drove prices down, but the rapid adoption and spread of internal combustion engines in the late 19th century helped create vast new markets. With only temporary interruptions, world petroleum consumption has expanded ever since.

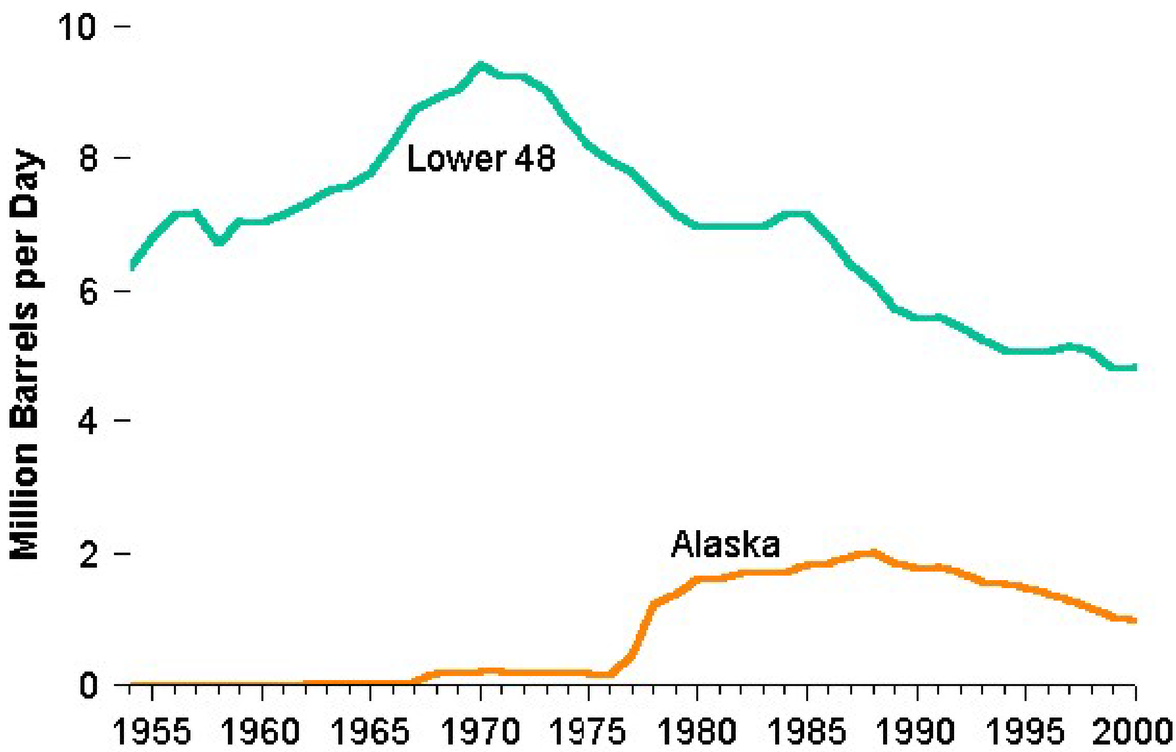
Until the 1950s the United States produced nearly all the petroleum it needed. But by the end of the decade the gap between production and consumption began to widen and imported petroleum became a major component of the U.S. petroleum supply (Figure 11). Beginning in 1994, the Nation imported more petroleum than it produced.

Figure 11. Petroleum Overview



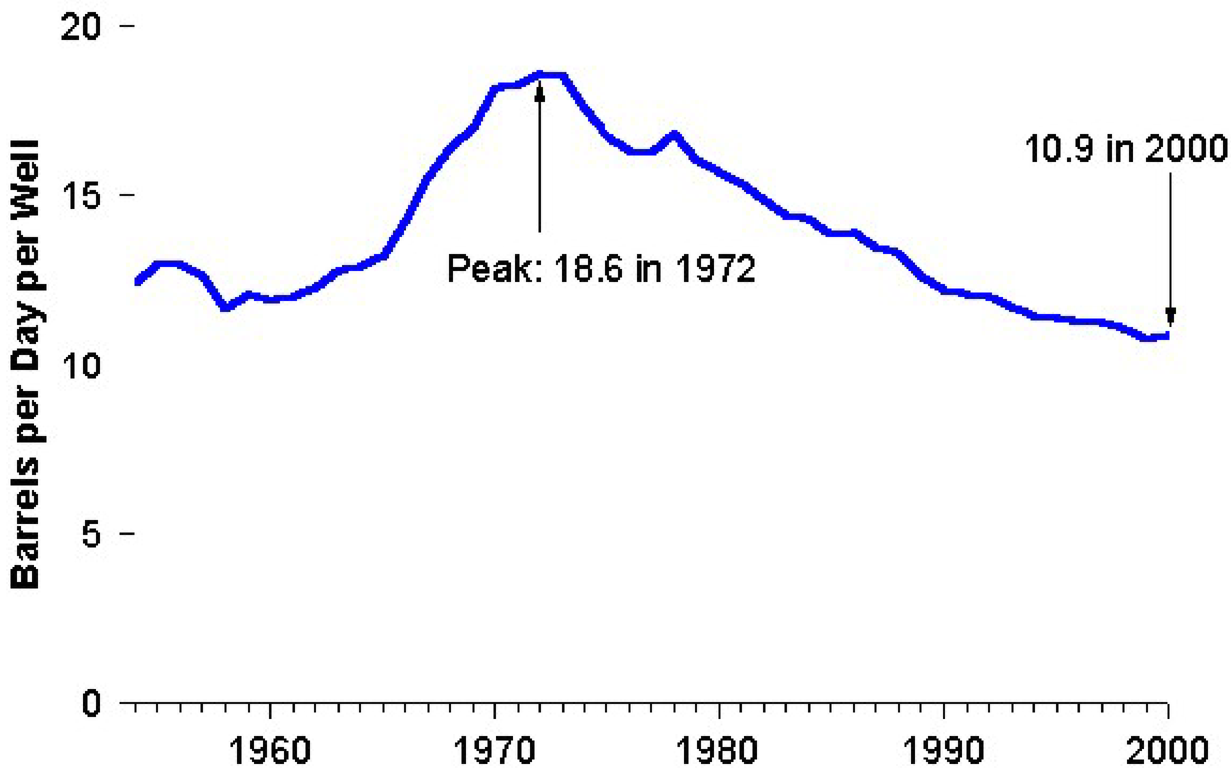
Crude oil production in the lower 48 States reached its highest level in 1970 at 9.4 million barrels per day (Figure 12). A surge in Alaskan oil output at Prudhoe Bay beginning in the late 1970s helped postpone the decline in overall U.S. production, but Alaska's production peaked in 1988 at 2.0 million barrels per day and fell to just under 1.0 million barrels per day per well in 2000.

Figure 12. Lower 48 and Alaskan Crude Oil Production



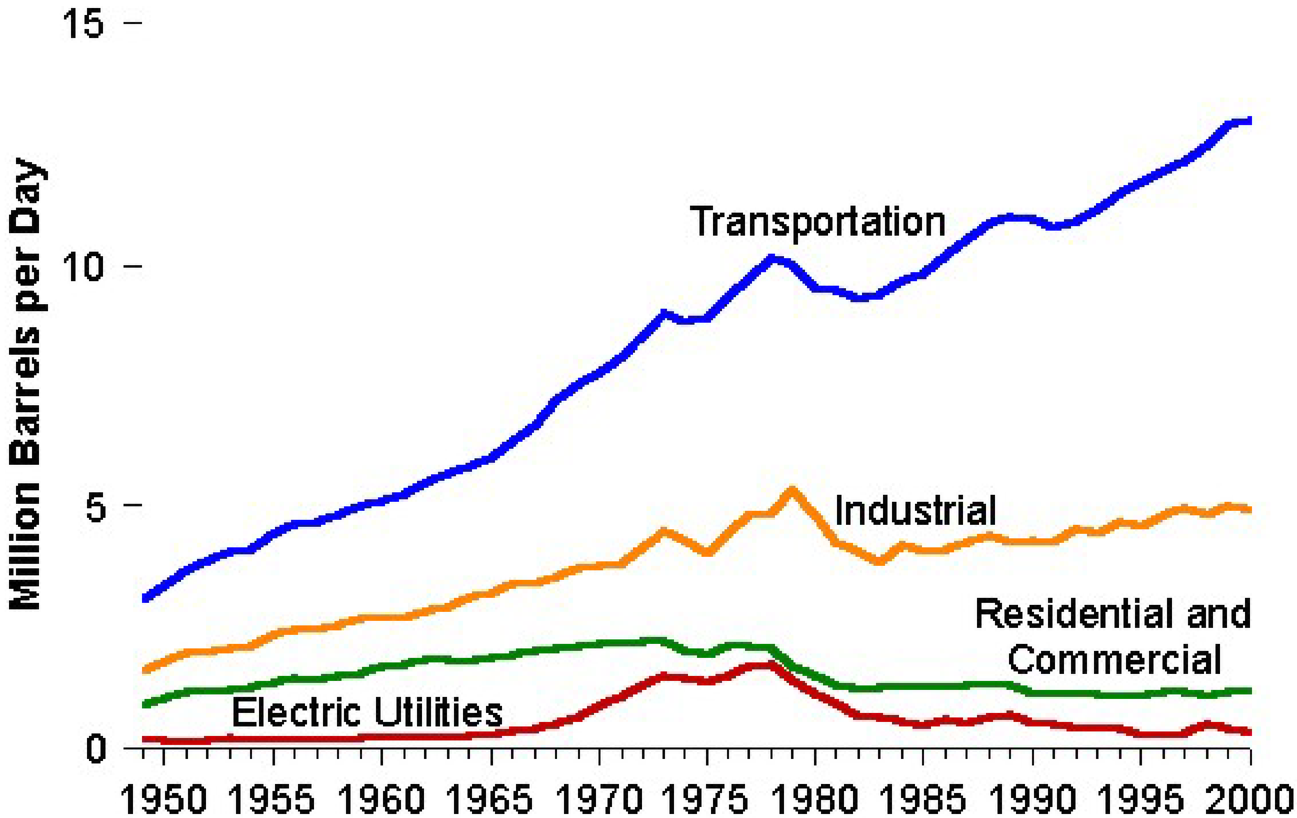
Another index of the Nation's petroleum output is oil well productivity, which fell from a high of 18.6 barrels per day per well in 1972 to 10.9 barrels per day per well in 2000 (Figure 13).

Figure 13. Oil Well Productivity



U.S. petroleum consumption rose annually until 1973, when the Arab OPEC embargo stalled the annual increases for two years. The increases then resumed, raising consumption to 18.8 million barrels per day in 1978, before rising prices drove it down to a post-embargo low of 15.2 million barrels per day in 1983. Consumption began to rebound the following year and was boosted by plummeting crude oil prices in 1986. By 2000 it had reached 19.4 million barrels per day. Of every 10 barrels of petroleum consumed in the United States in 2000, more than 4 barrels were consumed in the form of motor gasoline. The transportation sector alone accounted for two-thirds of all petroleum used in the United States in 2000 (Figure 14).

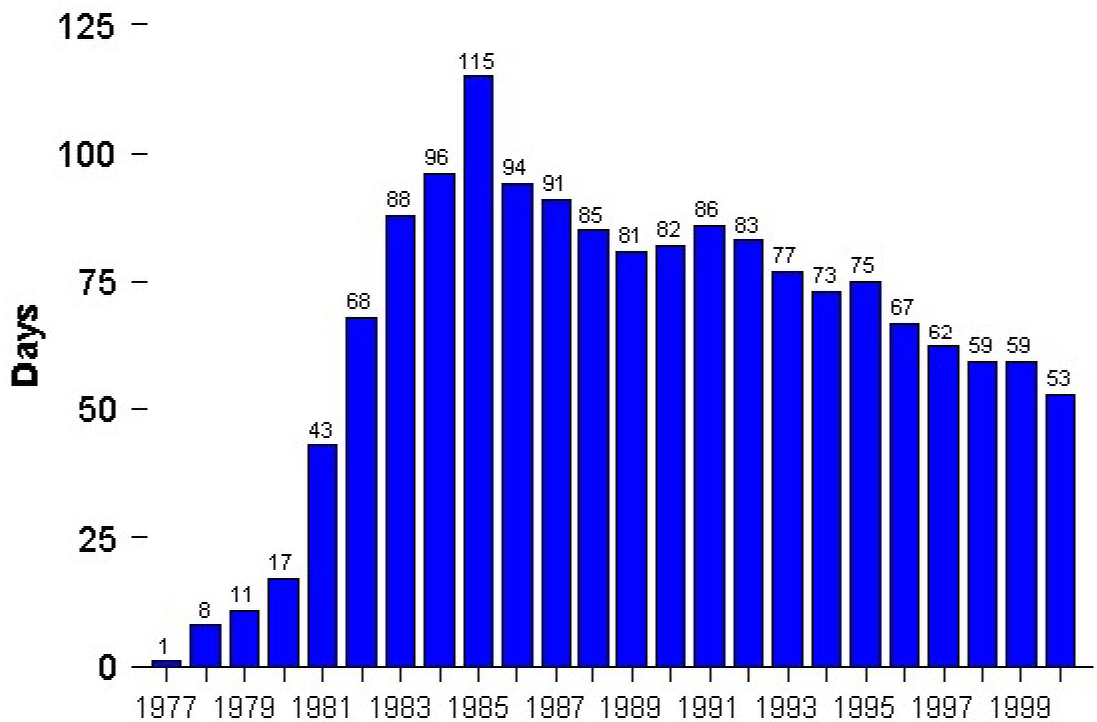
Figure 14. Petroleum Consumption by Sector



To meet demand, crude oil and petroleum products were imported at the rate of 11 million barrels per day in 2000, while exports measured 1 million barrels per day. Between 1985 (when net imports fell to a post-embargo low) and 2000, net imports of crude oil and petroleum products more than doubled from 4.3 million barrels per day to 10 million barrels per day. The share of U.S. net imports that came from OPEC nations reached 72 percent in 1977, subsided to 42 percent in 1985, and stood at 51 percent in 2000. Total net imports as a share of petroleum consumption reached a record high of 52 percent in 2000. The five leading suppliers of petroleum to the United States in 2000 were Canada, Saudi Arabia, Venezuela, Mexico, and Nigeria.

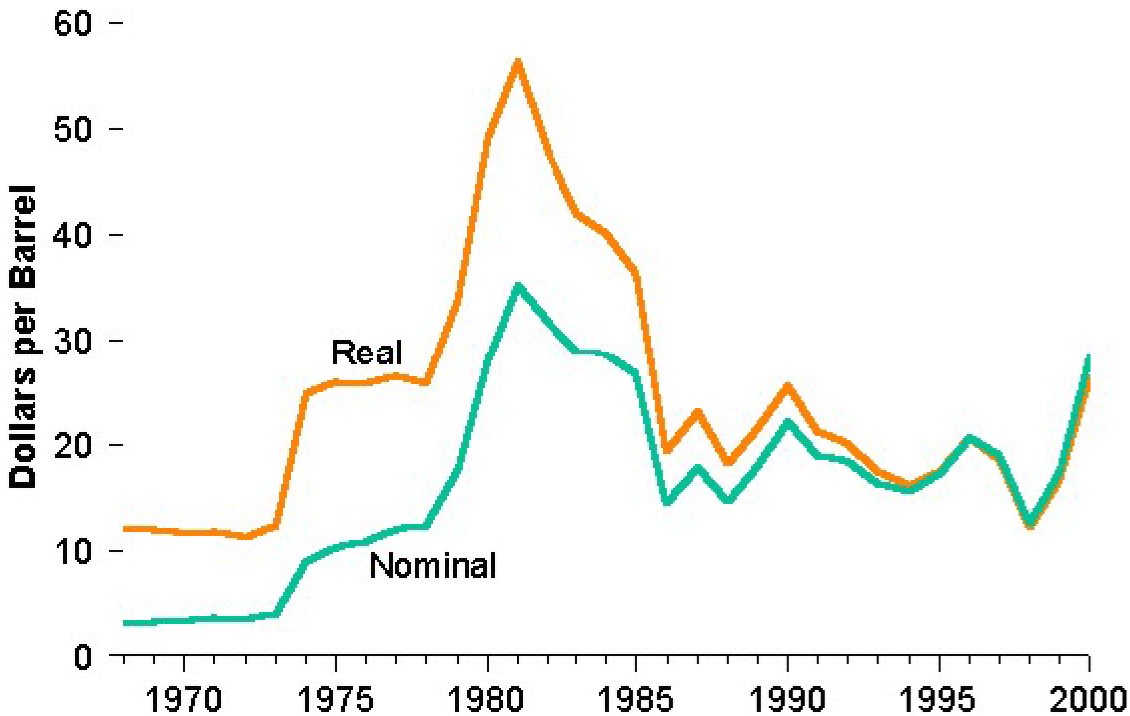
To protect against supply disruptions, the United States began to create a Strategic Petroleum Reserve in the late 1970s. By 1985 the reserve's holdings reached 493 million barrels, which would have provided enough crude oil to replace about 115 days' worth of net petroleum imports that year. In 2000, the reserve held 541 million barrels of crude oil. Due to the increased rate of imports, however, that amount would replace only 53 days' worth of net imported petroleum (Figure 15).

Figure 15. SPR Stocks as Days' Worth on Net Imports



U.S. petroleum prices rose steeply between 1998 and 2000. Refiners' acquisition costs for crude oil in 2000 (composite of domestic and imported oil costs) averaged $28.23 per barrel, a 16-year high. When adjusted for inflation, the cost was $26.40 per barrel (chained 1996 dollars), 58 percent above the previous year's cost--but still 53 percent below 1981's record of $56.50 per barrel (Figure 16).

Figure 16. Crude Oil Refiner Acquisition Cost



Natural Gas

Natural gas is mostly a mixture of methane, ethane, and propane, with methane making up 73 to 95 percent of the total. Often encountered when drilling for oil, natural gas was once considered mainly a nuisance. When either uses or--more likely today--accessible markets were lacking, it was simply flared (burned off) at the wellhead. Major flaring sites were sometimes the brightest areas visible in nighttime satellite images. Today, however, the gas is mostly reinjected for later use and to enhance oil production.

The first practical use of natural gas dates to 200 BCE and is attributed, like so many technical developments, to the Chinese. They used it to make salt from brine in gas-fired evaporators, boring shallow wells and conveying the gas to the evaporators via bamboo pipes. Natural gas was used extensively in Europe and North America in the 19th century as a lighting fuel, until the rapid development of electricity beginning in the 1890s ended that era. The development of steel pipelines and related equipment, which allowed large volumes of gas to be easily and safely transported over many miles, launched the modern natural gas industry. The first all-welded pipeline over 200 miles in length was built in 1925, from Louisiana to Texas. U.S. demand for natural gas grew rapidly thereafter, especially following World War II. Residential demand grew fifty-fold between 1906 and 1970.

The United States had large natural-gas reserves and was essentially self-sufficient in natural gas until the late 1980s, when consumption began to significantly outpace production (Figure 17). Imports rose to make up the difference, nearly all coming by pipeline from Canada, although small volumes were brought by tanker in liquefied form from Algeria and, in recent years, from a few other countries as well. Net imports as a share of consumption more than tripled from 1986 to 2000 (Figure 18).

Figure 17. Natural Gas Overview

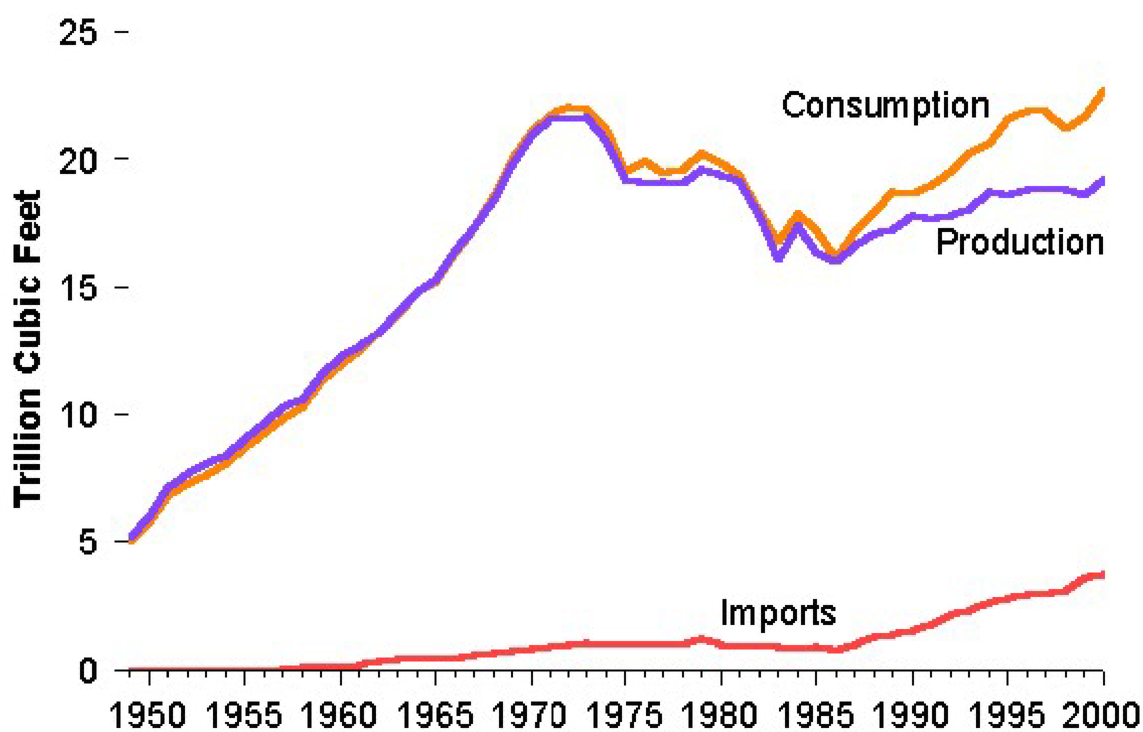
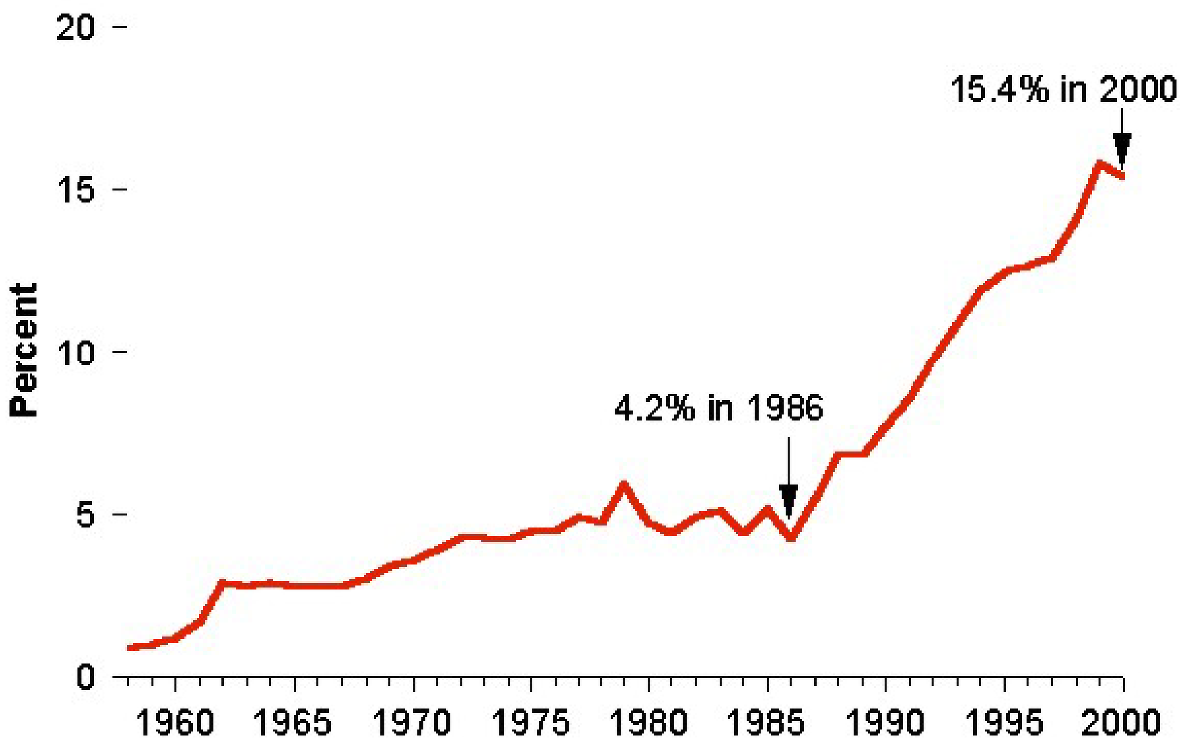
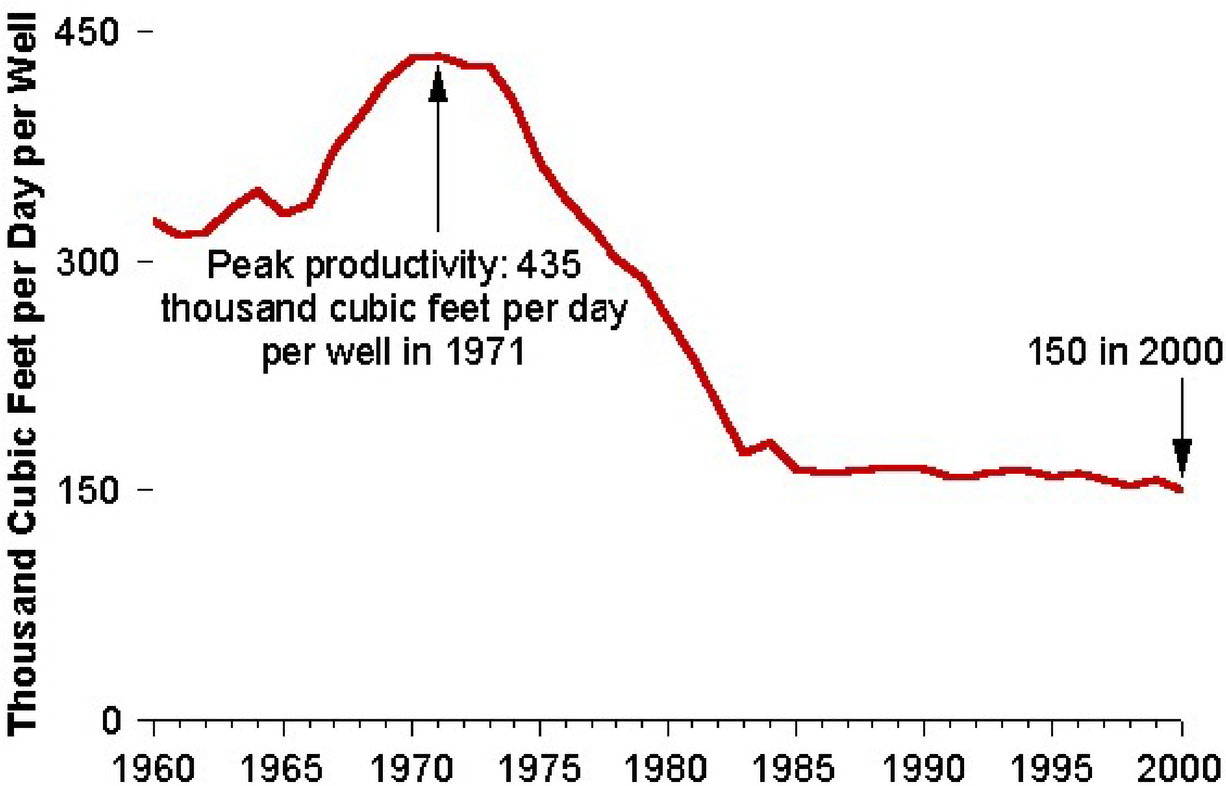


Figure 18. Net Imports as Share of Consumption



U.S. natural gas production in 2000 was 19.2 trillion cubic feet, well below the record-high 21.7 trillion cubic feet produced in 1973. Gas well productivity peaked at 435 thousand cubic feet per well per day in 1971, then fell steeply through the mid-1980s before stabilizing. Productivity in 2000 was 150 thousand cubic feet per well per day (Figure 19).

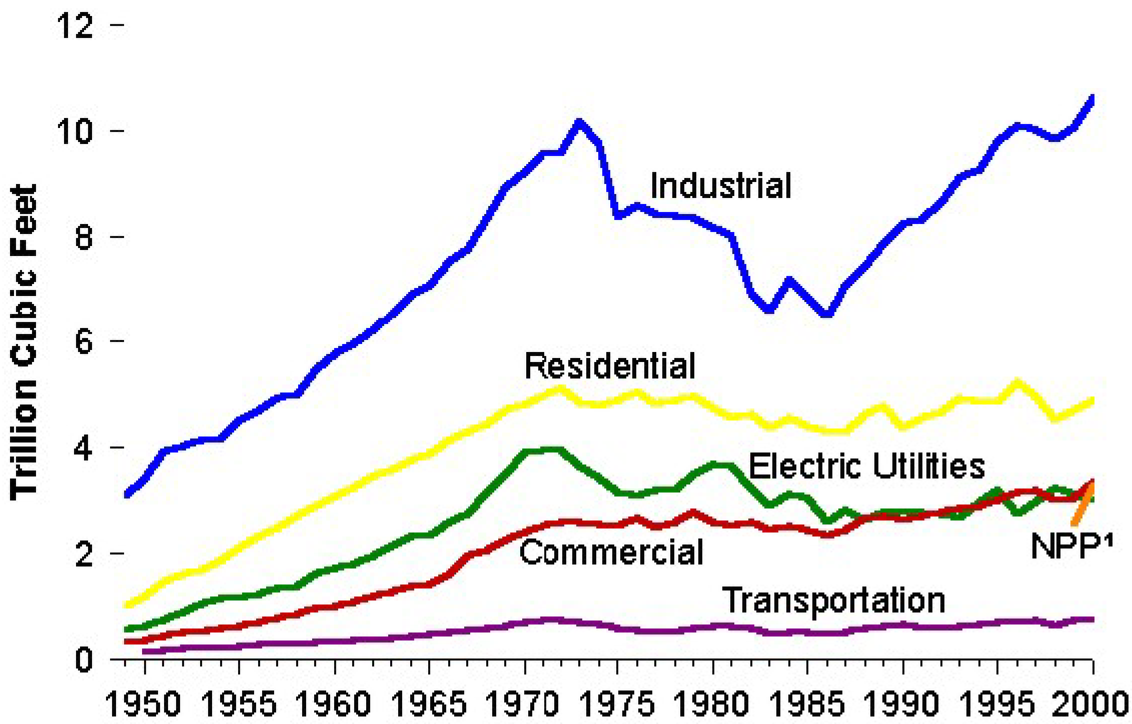
Figure 19. Natural Gas Well Productivity



Three States (Texas, Louisiana, and Oklahoma) account for over half of all natural gas produced in the United States. Texas alone produced 6.9 trillion cubic feet in 2000. Advancing drilling technology has made offshore sites more important, and over the last 2 decades about one-fifth of all U.S. production has come from offshore sites.

For decades, the industrial sector of the economy has been the heaviest user of natural gas (Figure 20). In 2000 industrial entities (including most electric power producers other than utilities) accounted for nearly half of all natural gas consumption, followed by the residential sector, which used another fifth of the total. In recent years, very small amounts of natural gas (about 6 billion cubic feet in 1999) have been reported for use in vehicles.

Figure 20. Natural Gas Consumption by Sector



NPP[1] = nonutility power producers

The price of natural gas at the wellhead (i.e., where the gas is produced) was $3.37 per thousand cubic feet in 2000, in real terms (chained 1996 dollars), up 63 percent over the previous year's price but well below the historical high of $3.76 per thousand cubic feet in 1983. In nominal dollars, the 2000 wellhead price was $3.60 per thousand cubic feet.

Coal

Scattered records of the use of coal as a fuel date from at least 1100 BCE. However, coal was not used widely until the Middle Ages, when small mining operations in Europe began to supply it for forges, smithies, lime-burners, and breweries. The invention of firebricks in the late 1400s, which made chimneys cheap to build, helped create a home heating market for coal. Despite its drawbacks (smoke and fumes), coal was firmly established as a domestic fuel by the 1570s. By that time, production in England was high enough that exports were thriving. Some of that coal eventually went to the American colonies.

The total amount of coal consumed in the United States in all the years before 1800 was an estimated 108,000 tons, much of it imported. The U.S. market for coal expanded slowly and it was not until 1885 that the young and heavily forested nation burned more coal than wood. However, the arrival of the industrial revolution and the development of the railroads in the mid-nineteenth century inaugurated a period of generally growing production and consumption of coal that continues to the present time. Today, the United States extracts coal in enormous quantities. In 1998 U.S. production of coal reached a record 1.12 billion short tons and was second worldwide after China. U.S. 2000 production was 1.08 billion short tons.

From 1885 through 1951, coal was the leading source of energy produced in the United States. Crude oil and natural gas then vied for that role until 1982. Coal regained the position of the top resource that year and again in 1984, and has retained it since. At 23 quadrillion Btu in 2000, coal accounted for nearly a third of all energy produced in the country.

Over the past several decades, coal production shifted from primarily underground mines to surface mines (Figure 21). In addition, the coal resources of Wyoming and other areas west of the Mississippi River underwent tremendous development (Figure 22).

Figure 21. Production by Mining Method

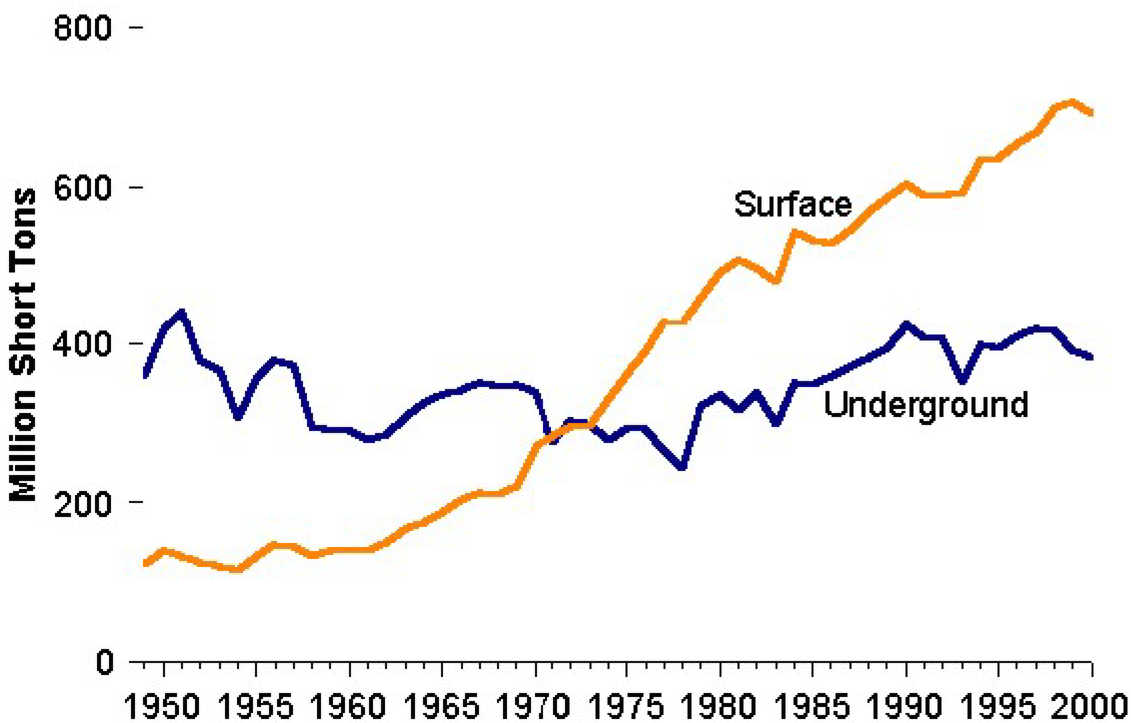
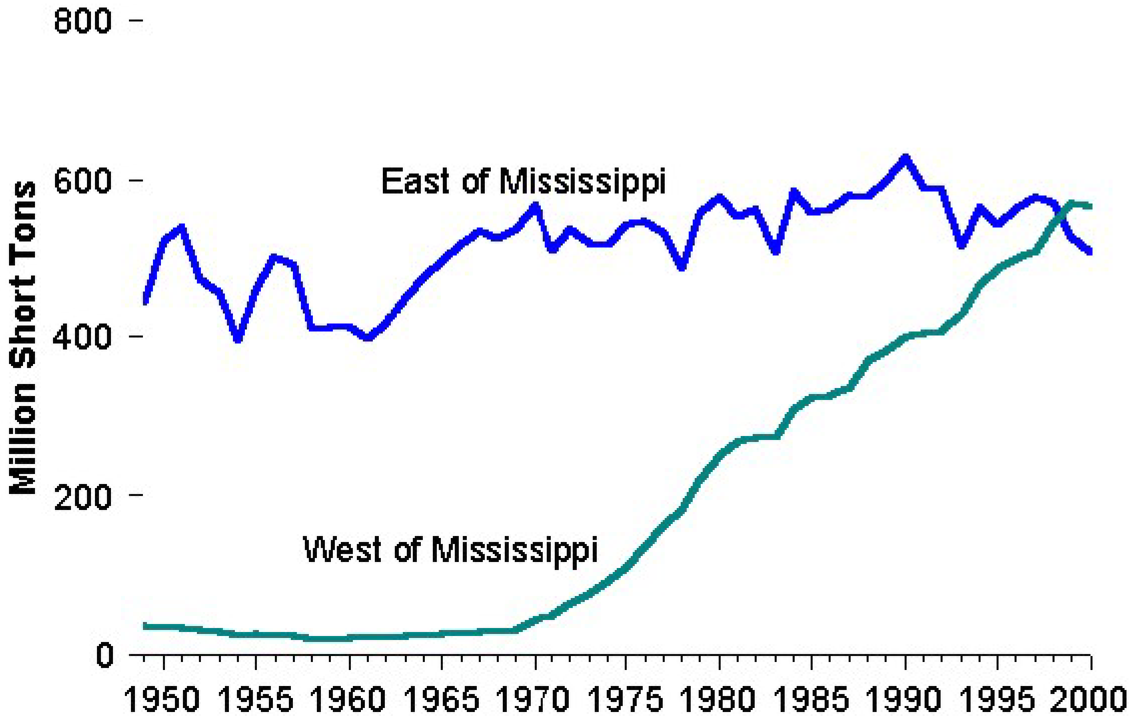


Figure 22. Production by Location



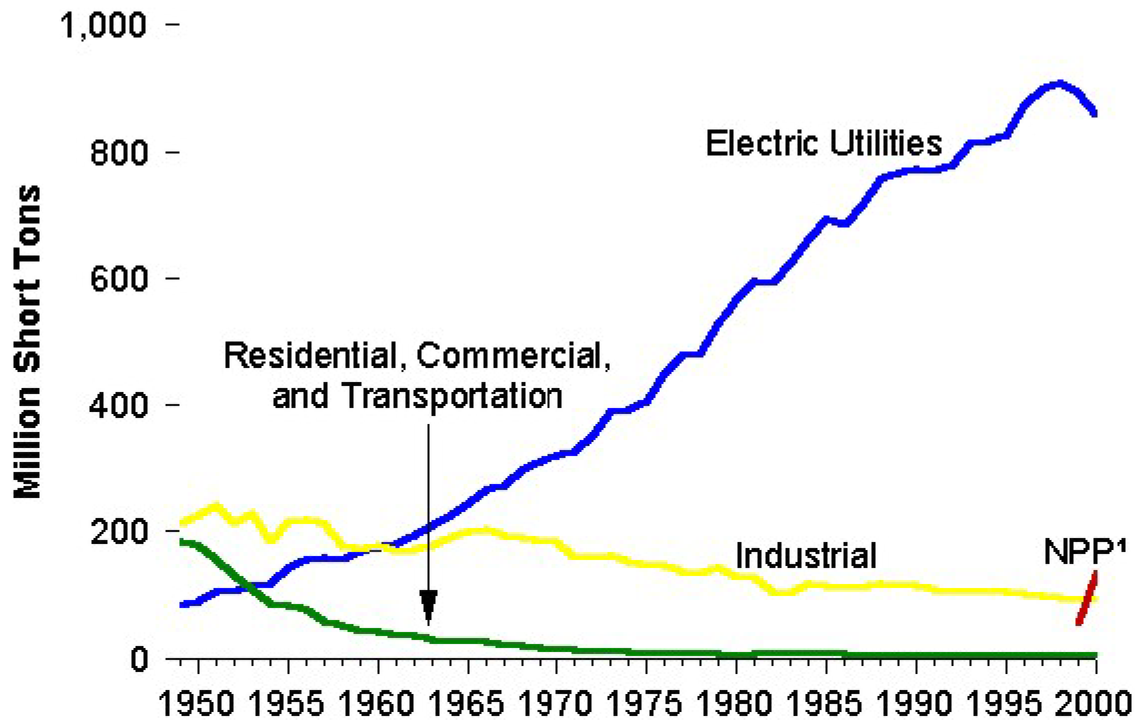
Technological improvements in mining and the shift toward more surface-mined coal, especially west of the Mississippi, have led to great improvements in coal mining productivity. In 1949 U.S. miners produced 0.7 short tons of coal per miner hour; by 1999 that rate had increased to 6.5 short tons per miner hour.

Since 1950, the United States has produced more coal than it has consumed. The excess production allowed the United States to become a significant exporter of coal to other nations. In 2000, coal exports totaled 58 million short tons, which accounted for 37 percent of all U.S. energy exports (in Btu terms). About 43 percent of the year's coal exports went to Europe. The top five purchasers of American coal were Canada, Brazil, Japan, Italy, and the United Kingdom. While the physical quantities of coal leaving the country are huge, in 2000 they represented only 6 percent of the Btu content of the petroleum coming into the United States.

The uses of coal in the United States have changed dramatically over the years. In the 1950s, most coal was consumed in the industrial sector, but many homes were still heated by coal and the transportation sector still consumed significant amounts in steam-driven trains and ships (Figure 23). In 2000 the industrial sector used less than half as much coal as in 1949 and only

9 percent of all coal consumed in the United States. The quantities that went to the residential, commercial, and transportation sectors were trivial. Electricity generation, however, used enormous amounts of coal and accounted for nearly 92 percent of all coal consumed in the United States in 2000.

Figure 23. Coal Consumption by Sector



NPP[1] = nonutility power producers

Coal-fired electric generating units emit gases that are of environmental concern. In 1999 U.S. carbon dioxide emissions from the combustion of coal for electric power generation were over half a billion metric tons of carbon, one-third of total carbon dioxide emitted from all U.S. fuel sources.

Except for a post-oil-embargo price spike that peaked in 1975, real (inflation adjusted) coal prices have generally fallen over the last half-century. The average price in 1999 was 47 percent lower than it was in 1949. Even before the steep price runups for natural gas and crude oil in 2000, coal was the least expensive of the major fossil fuels in this country. In nominal dollars, 2000 production prices for coal were 80 cents per million Btu compared with $3.24 per million Btu for natural gas and $4.61 per million Btu for crude oil.

Electricity

Electric power arrived barely a hundred years ago, but it has radically transformed and expanded our energy use. To a large extent, electricity defines modern technological civilization.

The reasons may not be easy to appreciate for those who have never known the filth, toil, and danger historically associated with obtaining and using such fuels as wood, coal, and whale oil. By contrast, at the point of use electricity is clean, flexible, controllable, safe, effortless, and instantly available. In homes, it runs everything from toothbrushes and televisions to heating and cooling systems. Outdoors, electricity guides traffic, aircraft, and ships, and lights up the night. In business and industry, electricity enables virtually instantaneous global communication and powers everything from trains, auto plant assembly lines, and restaurant refrigerators to the computers that run the New York Stock Exchange and the automatic pin-setting machines at the local bowling alley.

Electric power developed slowly, however. Humphrey Davy built a battery-powered arc lamp in 1808 and Michael Faraday an induction dynamo in 1831, but it was another half-century before Thomas Edison's primitive cotton-thread filament burned long enough to prove that a workable electric light could be made. Once past that hurdle, progress accelerated. Edison opened the first electricity generating plant (in London) less than 3 years later, in January 1882, and followed with the first American plant (in New York) in September. Within a month, electric current from New York's Pearl Street station was feeding 1,300 lightbulbs, and within a year, 11,000--each a hundred times brighter than a candle. Edison's reported goal was to "make electric light so cheap that only the rich will be able to burn candles."

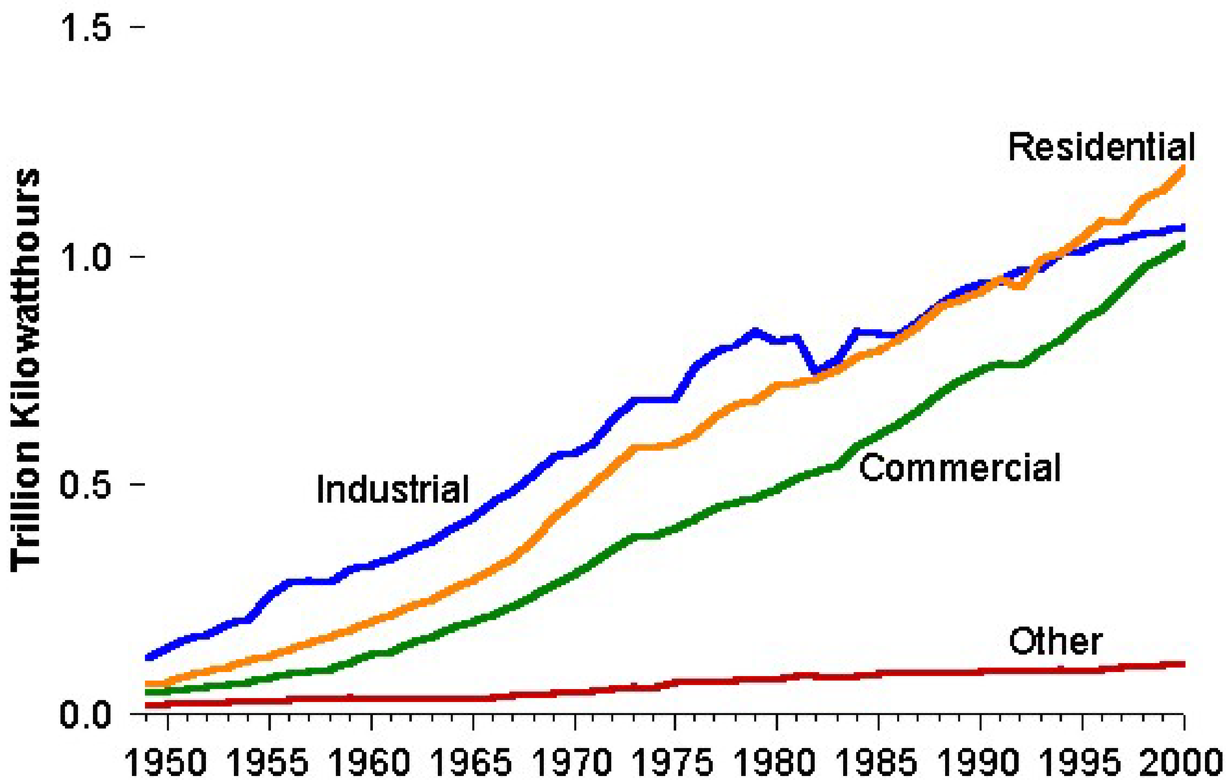
Though Edison fathered the electric utility industry, other companies surpassed him in building central power stations and his stubborn faith in direct current (DC) betrayed him. DC could only be transmitted 2 miles, while a rival alternating-current (AC) system developed by George Westinghouse and Nikola Tesla (whom Edison had fired) enabled long-distance transmission of high-voltage current and stepdowns to lower voltages at the point of use--essentially the system in place today. Edison even subsidized construction of an AC-powered electric chair to convince the public that AC was dangerous, but to no avail.

The process of electrification proceeded in fits and starts. Industries like mining, textiles, steel, and printing electrified rapidly during the years between 1890 and 1910. Electricity's penetration of the residential sector was slowed by competition from gas companies, which had a large stake in the lighting market. Nevertheless, by 1900 there were 25 million electric incandescent lamps in use and homeowners had been introduced to electric stoves, sewing machines, curling irons, and vacuum cleaners. Generating equipment and distribution systems developed in parallel to meet the rising demand. By 1903 utility executive Samuel Insull had commissioned a 5 megawatt steam-driven turbine generator--the first of its type and the largest of any generator then built--and launched a revolution in generating hardware.

The cities received electric service first, because it has always been cheaper, easier, and more profitable to supply large numbers of customers when they are close together. High costs and the Great Depression, which dried up most investment capital, delayed electric service to rural Americans until President Franklin Roosevelt signed into law the Rural Electrification Administration (REA) in 1935. The REA loaned money at low interest and helped to set up electricity cooperatives. Though interrupted by World War II, rural electrification proceeded rapidly thereafter. By 1967 more than 98 percent of American farms were using electricity from central station power plants.

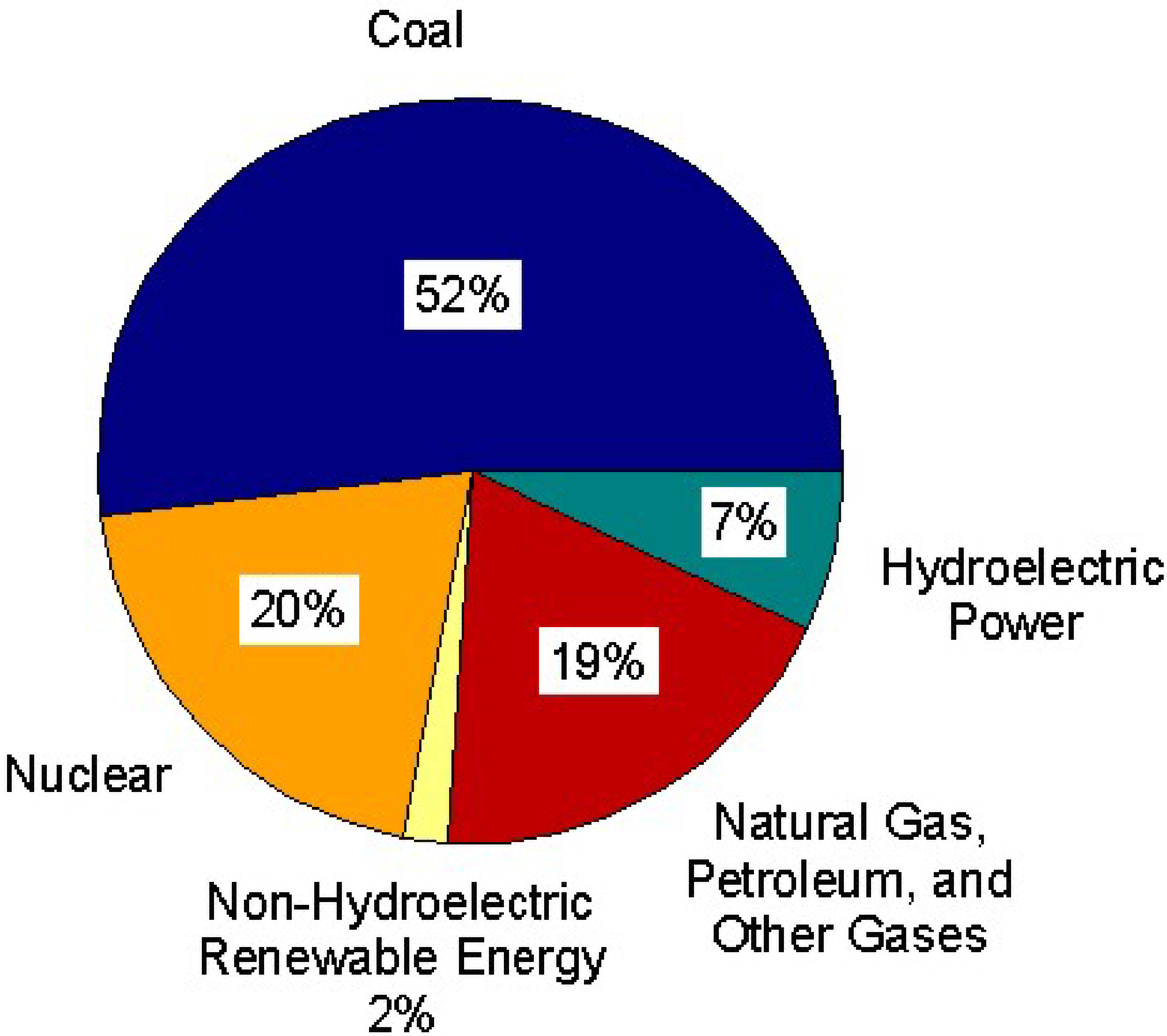
The depth of electricity's penetration into our economy and way of life is reflected in the fact that, over the last half century, annual increases in total electricity end-use faltered only twice, in 1974 and 1982. From 1949 to 2000, while the population of the United States expanded 89 percent, the amount of electricity use grew 1,315 percent. Per-capita average consumption of electricity in 2000 was more than seven times as high as in 1949. Electricity's broad usage in the economy can be seen in the sector totals, which were led in 2000 by the residential sector, followed closely by the industrial sector, and then the commercial sector (Figure 24).

Figure 24. Electric Utility Retail Sales by Sector



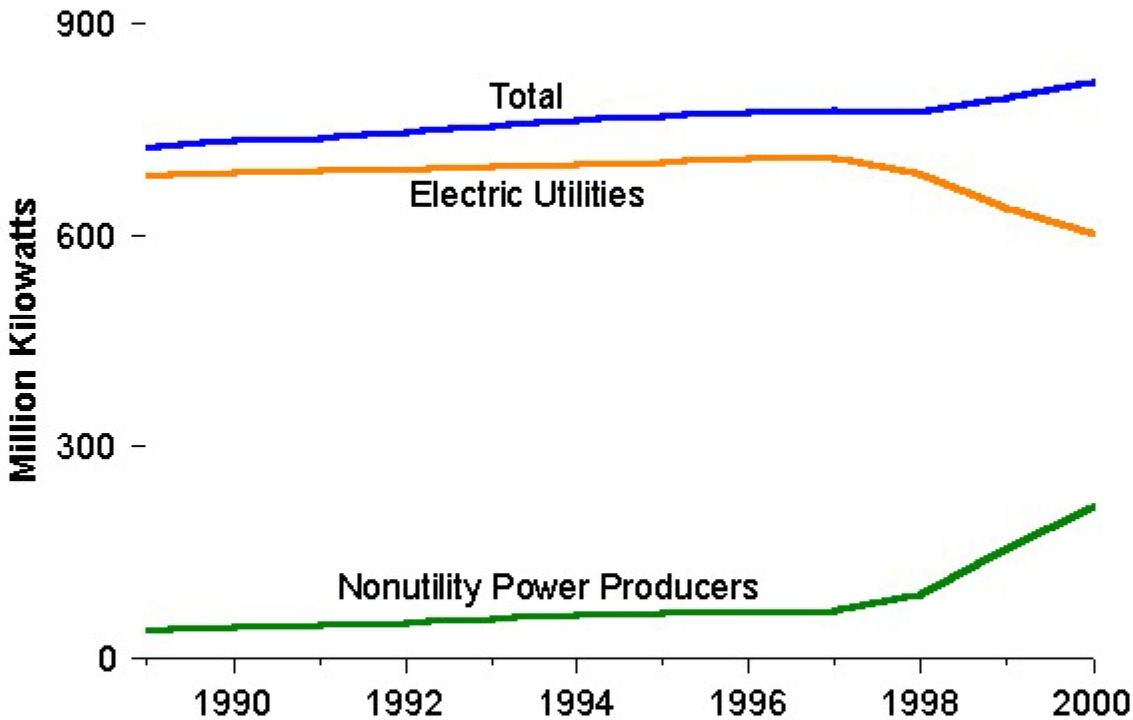
Where does all this electricity come from? In the United States, coal has been and continues to be the source of most electricity, accounting for over half of all electricity generated by the electric power sector in 2000 (Figure 25). Hydroelectric power was an early source of U.S. electricity--accounting for almost a third of all generation in 1949--and remains a dependable contributor (over 7 percent of the total in 2000). Natural gas and petroleum grew steadily as sources of electricity in the late 1960s. Their combined usage peaked at 37 percent of the total in 1972 and stood at 19 percent in 2000. Meanwhile, a new source entered the picture: nuclear electric power. A trickle of nuclear electricity began flowing in 1957, and the stream widened steadily except for downturns in 1979 and 1980, following the accident at Three Mile Island, and again in 1993 and 1997. In 2000 nuclear power accounted for 20 percent of total electricity generation.

Figure 25. Electricity Net Generation by Source for 2000



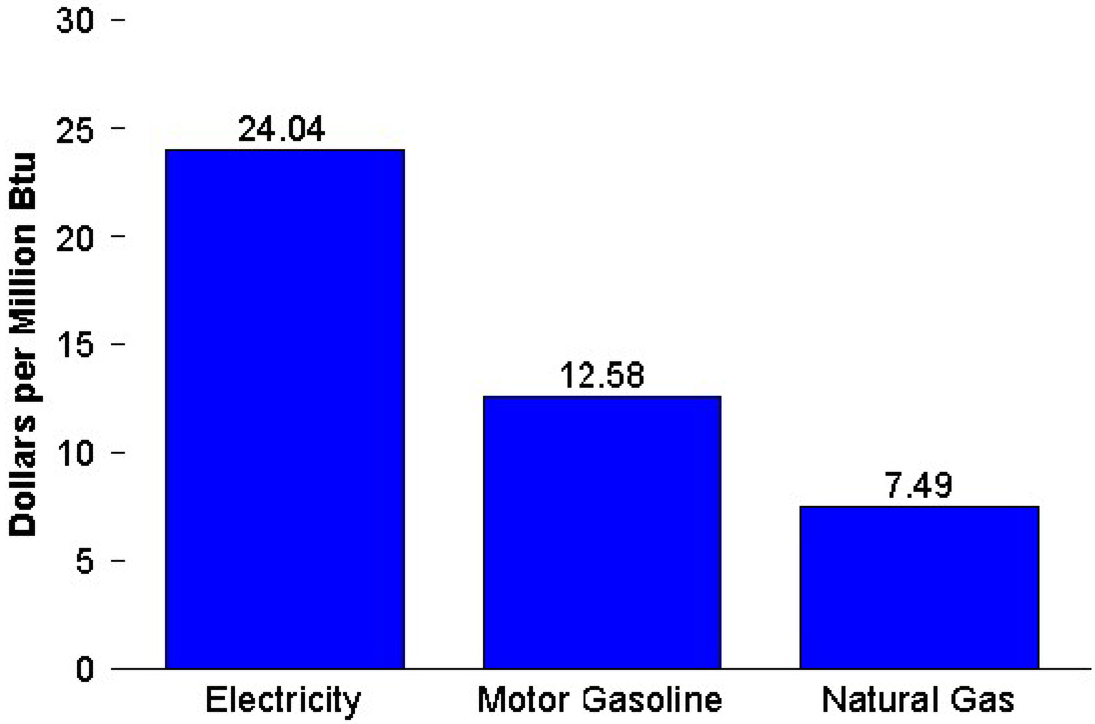
Just as electricity's applications and sources change over time, so is the structure of the electric power sector itself evolving. The sector is now moving away from the traditional, highly regulated organizations known for decades as electric utilities and toward an environment marked by lighter regulation and greater competition from and among nonutility power producers. In 2000, nonutility power producers (such as independent power producers and nonutility cogenerators) accounted for 26 percent of total net summer capability, up from 20 percent in 1999 (Figure 26).

Figure 26. Electric Power Sector Net Summer Capability



Electricity's great assets as a form of energy are reflected in its cost to the end user. The price paid by the consumer includes the cost of converting the energy from its original form (such as coal) into electricity and the cost of delivering it. In 2000 consumers paid an average of $24.06 per million Btu for the electricity delivered to their residences (Figure 27). In contrast, consumers paid an average of only $7.49 per million Btu for the natural gas used in their homes and an average of $12.58 per million Btu for the motor gasoline to fuel their vehicles.

Figure 27. Consumer Prices for Electricity, Natural Gas, and Motor Gasoline for 2000



The unit cost of electricity is high because most of the energy that must be purchased to generate it does not actually reach the end user but is expended in creating the electricity and moving it to the point of use. In 2000, for example, approximately 40 quadrillion Btu of energy were consumed by the electric power sector to generate electricity in the United States, but only 12 quadrillion Btu worth of electricity were actually used directly by consumers. Where did the other 28 quadrillion Btu go? Energy is never destroyed but it does change form. The chemical energy contained in fossil fuels, for example, is converted at the generator to the desired electrical energy. Because of theoretical and practical limits on the efficiency of conversion equipment, much of the energy in the fossil fuels is "lost," mostly as waste heat. (The overall energy efficiency of a system can be increased through the tandem production of electricity and some form of useful thermal energy. This process, known as cogeneration, reduces waste energy by utilizing otherwise unwanted heat in the form of steam, hot water, or hot air for other purposes, such as operating pumps or for space heating or cooling.)

In addition to the conversion losses, line losses occur during the transmission and distribution of electricity as it is transferred via connecting wires from the generating plant to substations (transmission), where its voltage is lowered, and from the substations to end users (distribution), such as homes, hospitals, stores, schools, and businesses. The generating plant itself uses some of the electricity. In the end, for every three units of energy that are converted to create electricity, only about one unit actually reaches the end user.

Nuclear Energy

Of all the major forms of energy now in use, only nuclear power has truly modern roots. The central insight--that the controlled fission of heavy elements could release enormous energies--came to British physicist Ernest Rutherford in 1904. Research during the 1930s convinced scientists that such a controlled chain reaction was possible, and Enrico Fermi's group first achieved one in December 1942 at the University of Chicago, in a crude graphite-moderated reactor built on a vacant squash court.

World War II postponed further progress toward commercial nuclear electric power, but the theoretical foundation had been established and several factors encouraged nuclear power's development when peace returned. It was believed that fuel costs would be negligible and therefore that nuclear power would be relatively inexpensive. In addition, both the United States and Western Europe became net importers of crude oil in the early 1950s and nuclear power was seen as critical to avoiding energy dependence. Geopolitics appear to have played a role as well; President Dwight Eisenhower's Atoms for Peace program was intended in part to divert fissionable materials from bombs to peaceful uses such as civilian nuclear power.

In 1951 an experimental reactor sponsored by the U.S. Atomic Energy Commission generated the first electricity from nuclear power. The British completed the first operable commercial reactor, at Calder Hall, in 1956. The U.S. Shippingport unit, a design based on power plants used in nuclear submarines, followed a year later. In cooperation with the U.S. electric utility industry, reactor manufacturers then built several demonstration plants and made commitments to build additional plants at fixed prices. This commitment helped launch commercial nuclear power in the United States.

The success of the demonstration plants and the growing awareness of U.S. dependency on imported crude oil led to a wave of enthusiasm for nuclear electric power that sent orders for reactor units soaring between 1966 and 1974 (Figure 28). The number of operable units increased in turn, as ordered units were constructed, tested, licensed for full power operation, and connected to the electricity grid (Figure 29). However, the curve of operable units lagged behind the curve of ordered units somewhat because of the long construction times required for the large, complex plants. The total number of U.S. operable reactor units peaked in 1990 at 112.

Figure 28. Nuclear Generation Unit Orders and Permits

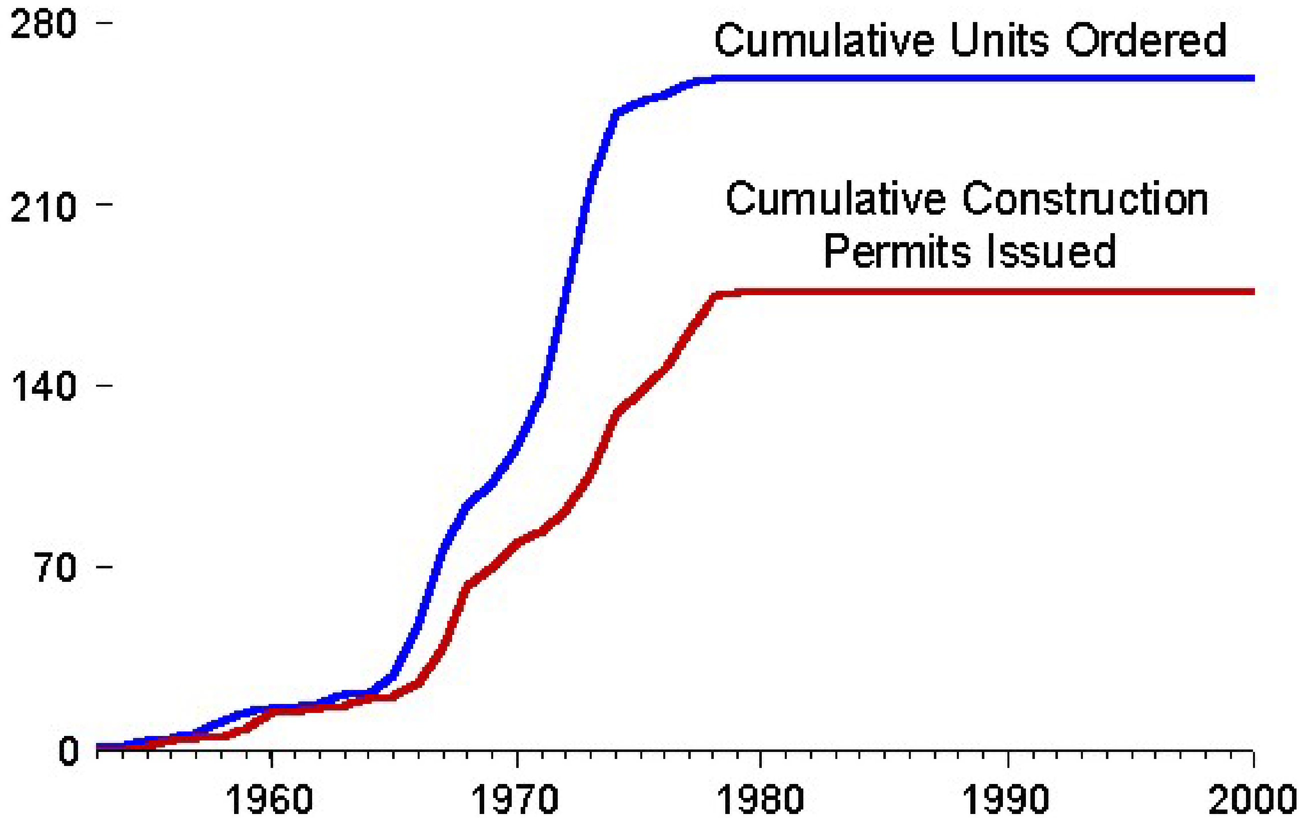
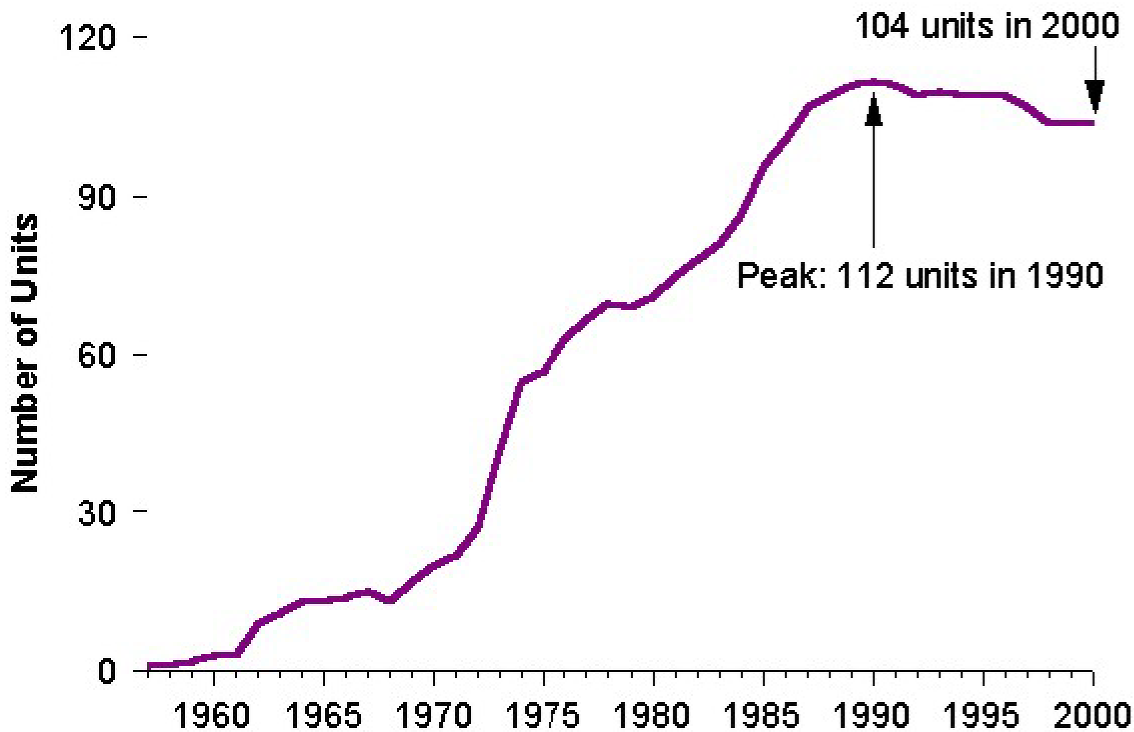


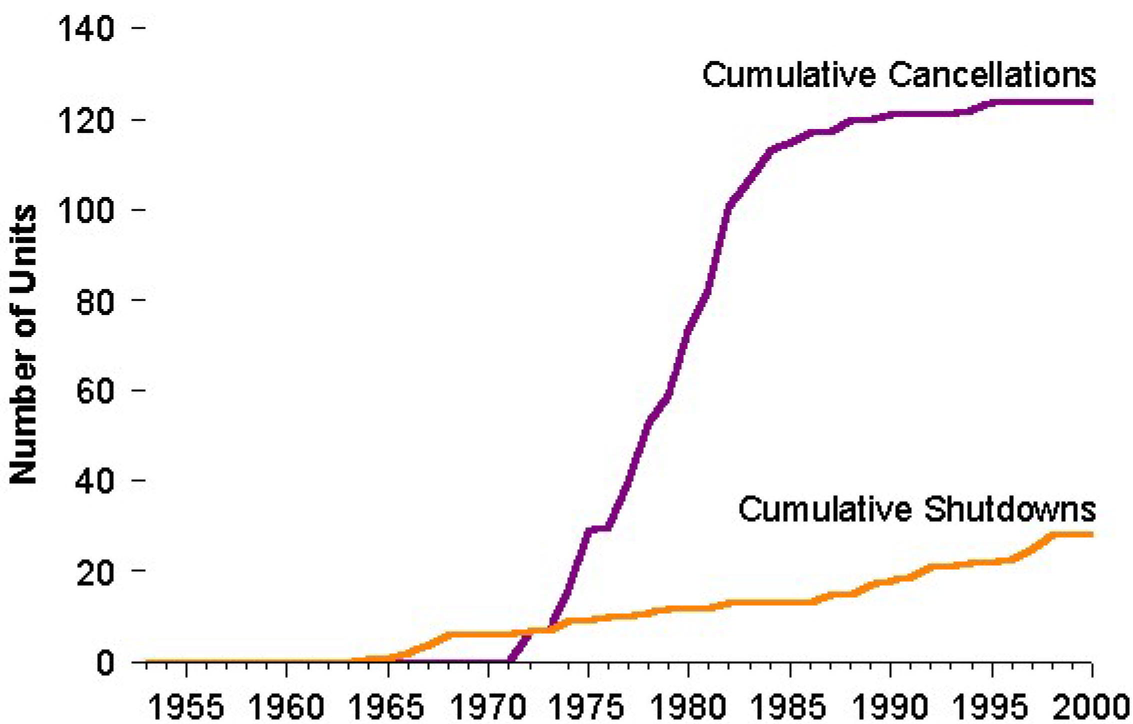
Figure 29. Number of Operable Units



Orders for new units fell off sharply after 1974. Of the total of 259 units ordered to date, none was ordered after 1978. Although safety concerns, especially after the accident at Three Mile Island in 1979, reinforced a growing wariness of nuclear power, the chief reason for its declining momentum in the United States was economic. The promise of nuclear electric power had been that it would, in the now-famous phrase, make energy "too cheap to meter." In reality, nuclear power plants have always been costly to build and, for several reasons, became radically more costly between the mid-1960s and the mid-1970s. Utilities began building large plants before much experience had been gained with small ones. Expected economies of scale did not materialize. Many units were forced to undertake costly design changes and equipment retrofits, partially as a result of the Three Mile Island accident. Meanwhile, nuclear power plants have also had to compete with conventional coal- or natural gas-fired plants with declining operating costs.

These trends disillusioned many utilities and investors. Interest in further orders subsided and many ordered units were canceled before they were built. By the end of 2000, 124 units had been canceled, 48 percent of all ordered units (Figure 30).

Figure 30. Unit Cancellations and Shutdowns



The average capacity factor of U.S. nuclear units--the ratio of the electricity they actually produced in a given year to the electricity they could have produced if run at continuous full power--has improved steadily over the years, and reached 88 percent in 2000. However, as operable nuclear power plants have aged, some have become uneconomic to operate or have otherwise reached the end of their useful lives. By the end of 2000, 28 once-operable units had been shut down permanently. The joint effect of shutdowns and lack of new units coming on line is that the number of U.S. operable units has fallen off since 1990 to 104. In its *Annual Energy Outlook 2001*, EIA projects that 27 percent of the nuclear generating capacity that existed at the end of 1999 will be retired by 2020. No new plants are expected to be built during the period.

Renewable Energy

For all but the most recent fraction of humanity's time on Earth, virtually all energy was renewable energy. Before the widespread use of fossil fuels and nuclear power, which arrived only a relative eyeblink ago, our ancestors warmed themselves directly in the sun, burned brush and fuelwood fashioned by photosynthesis from sunlight and nutrients, harnessed the power of wind and water created mainly by sun-driven atmospheric and hydrologic cycles, and of course used their own musclepower and that of animals.

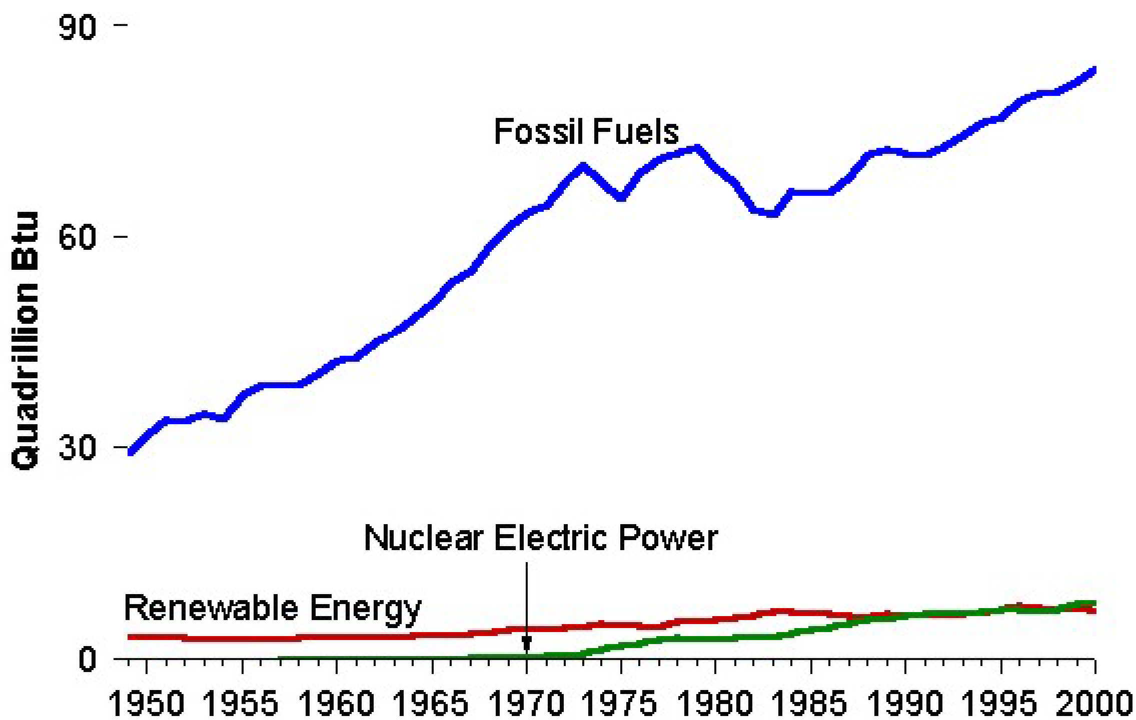
We still depend heavily on renewable energy in these basic forms. But various cultures have also found more inventive means of harnessing renewable resources, from mounting sails on wheelbarrows, as did ancient Chinese laborers, to gathering and burning buffalo dung, as did Native Americans and European settlers making their way west. The story of renewable energy is one of the invention and refinement of technologies for extracting both more energy and more useful forms of it from a wider variety of renewable sources. Many energy experts believe that the age of fossil fuels is only an interlude between pre- and post-industrial eras dominated by the use of renewable energy.

Some renewable energy technologies, such as water- and wind-driven mills, have been in use for centuries. Grain mills powered by waterwheels have existed since at least the first century BCE and became commonplace long ago. In England, for example, the Domesday Book survey of 1086 counted 5,624 mills in the south and east alone. They were to be found throughout Europe and elsewhere and were used for a wide variety of mechanical tasks in addition to milling, from pressing oil to making wire. Some installations were surprisingly large. The Romans built a mill with 16 wheels and an output of over 40 horsepower near Arles in France. A giant 72-foot waterwheel with an output of 572 horsepower, dubbed Lady Isabella, was erected at a mine site on the Isle of Man in 1854. Further development of waterwheels ended with the invention of water turbines. Both types of machines were supplanted by large steam engines, which could be sited nearly anywhere. Turbines, however, found an important niche with the development of hydroelectric power.

Windmills are a younger but still ancient technology, dating at least to the 10th century in the Middle East, a bit later in Europe. In one form or another, windmills have remained in use ever since, for milling grain, pumping water, working metal, sawing, and crushing chalk or sugar cane. As mentioned in the introduction, American farms of the 19th century erected millions of small windmills to pump water for livestock or household use. In the modern era, technologically advanced windmills have been developed for generating electricity.

Modern renewable sources in the United States contribute about as much to total energy consumption as does nuclear power (Figure 31). Hydroelectric power generation, which uses dam-impounded water to drive turbine generators, generally accounts for a large share of U.S. renewable energy output. In 2000 (a relatively bad year for U.S. hydropower) that share was 46 percent of total renewable energy consumption. The American hydropower infrastructure includes the great dams of the intermountain West, the Columbia basin, and the Tennessee River valley, as well as hundreds of other smaller installations nationwide.

Figure 31. Energy Consumption by Source



Much of U.S. renewable energy comes from wood and waste, a diverse category that accounted for almost half of the total in 2000. It includes not only the obvious candidates (such as wood, methanol, and ethanol) but also peat, wood liquors, wood sludge, railroad ties, pitch, municipal solid waste, agricultural waste, straw, tires, landfill gas, fish oil, and other things. Wood and wood byproducts are the most heavily used form of biomass and are an important source of energy for such industries as paper manufacturing and lumber, which have ready access to them. Geothermal, which began supplying a measurable amount of energy in 1960, accounted for 5 percent of U.S. renewable energy in 2000.

Despite their cachet, solar energy (photovoltaic and thermal) and wind energy contribute relatively little to the renewable total (about 1 percent each in 2000). The peak year for U.S. manufacturers' shipments of solar thermal collectors was 1981, when 21 million square feet were shipped. During the 1990s, shipments averaged less than half that level, though the 1999 total of

8.6 million square feet was the highest since 1990. Ninety-one percent of the 1999 total went to the residential sector, and 95 percent of the newly shipped collectors were used to heat swimming pools. Four percent were used to heat water. Inflation-adjusted prices for photovoltaic cells have generally declined in recent years and the volume of shipments (expressed as peak kilowatts) has risen steadily since 1985. Over 70 percent of U.S. production went for export in 1999. Wind energy production rose 113 percent between 1989 and 2000 but remains a small factor in the U.S. renewable energy picture.

Environmental Indicators

The use of energy brings both benefits and costs. Some, but not all, of these costs show up on consumers' utility bills. The charges levied on consumers by an energy producer (an electric utility with a coal-fired generating plant, for instance) are designed to cover the producer's costs of building the power plant, extracting coal from the ground, transporting it to the power plant, crushing it to the proper size for combustion, maintaining the generating turbines, paying workers and managers, and so on.

One important category of costs that is often not reflected in consumers' bills is energy-related environmental effects. These unwanted effects can be thought of as the tail end of the energy cycle, which begins with extraction and processing of fuels (or gathering of wind or solar energy), proceeds with conversion to useful forms by means of petroleum refining, electricity generation, and other processes, and then concludes with distribution to, and consumption by, end-users. Once the energy has rendered the services for which it is consumed, all that is left are the byproducts of energy use, i.e., waste heat, mine tailings, sulfur dioxide and carbon dioxide gases, spent nuclear fuel, and many others.

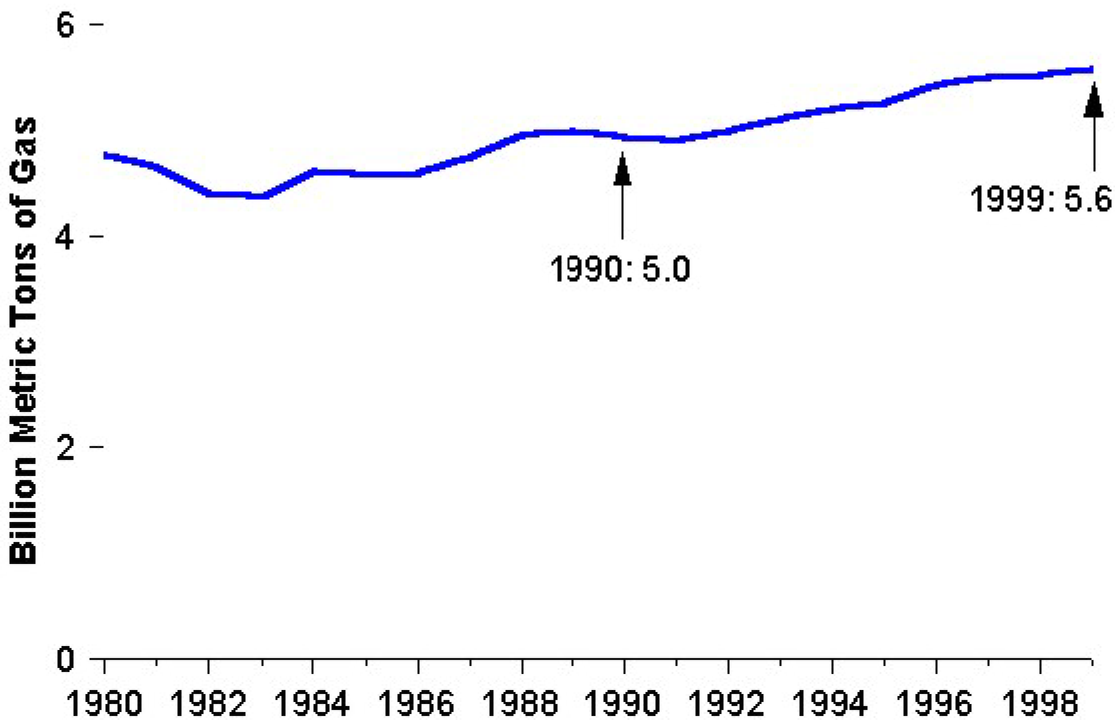
All energy use has unwanted effects of one kind or another; even a simple campfire produces eye-stinging smoke as well as warmth. Such effects can be local or widespread and have long provoked concern. King Edward I of England, for instance, so objected to the noxious smoke and fumes from London's many coal-burning fires that in 1306 he tried (unsuccessfully) to ban its use by anyone except blacksmiths.

The enormous scale of modern energy use has sharply increased concerns about unwanted environmental effects. No form of energy production is entirely free of them, including renewable energy. Damming rivers and streams for hydropower facilities radically alters natural stream flows in ways that can threaten or endanger aquatic species. Wind-turbine generators can make noise and kill birds. Biomass generating plants that rely on plantation forestry for fuel can displace natural forest habitat and reduce biological diversity.

Among the most significant environmental effects of energy production and consumption is the emission of greenhouse gases. These gases--carbon dioxide, methane, nitrous oxide, and others--block infrared radiation from the Earth to space and retain the captured heat in the atmosphere. This greenhouse effect keeps the Earth's climate hospitable to life. But the possibility of carbon-dioxide-forced warming of the climate--postulated since 1861--concerns scientists, and in recent years many have come to believe that anthropogenic (human-caused) additions to greenhouse gases are raising global average temperatures and may produce harmful changes in the global climate. Energy-related greenhouse gas emissions make up a significant fraction of all such emissions, and the United States, as one of the world's largest producers and consumers of fossil fuels, is responsible for a major portion of global energy-related emissions.

Carbon dioxide (CO_2) accounts for the largest share of combined anthropogenic greenhouse gas emissions. In 1999 U.S. anthropogenic CO_2 emissions totaled about 5.6 billion metric tons (of gas; 1 ton of carbon equals 3.667 tons of carbon dioxide gas), 17 percent higher than in 1980 and 28 percent higher than in 1983, the low point of the 20-year period from 1980 through 1999 (Figure 32). Nearly 99 percent of this total was energy-related emissions, especially from petroleum consumed by the transportation sector, coal burned by electric utilities, and natural gas used by industry, homes, and businesses.

Figure 32. Carbon Dioxide Emissions



Energy-related emissions of methane, another important greenhouse gas, remained at about 11 million metric tons in 1999. While about 37 percent of U.S. methane emissions stemmed from energy use, most came from landfills and such agricultural sources as ruminant animals (cattle and sheep) and their wastes. Emissions of a third potent greenhouse gas, nitrous oxide, remained about the same in 1999, at 1.2 million metric tons.

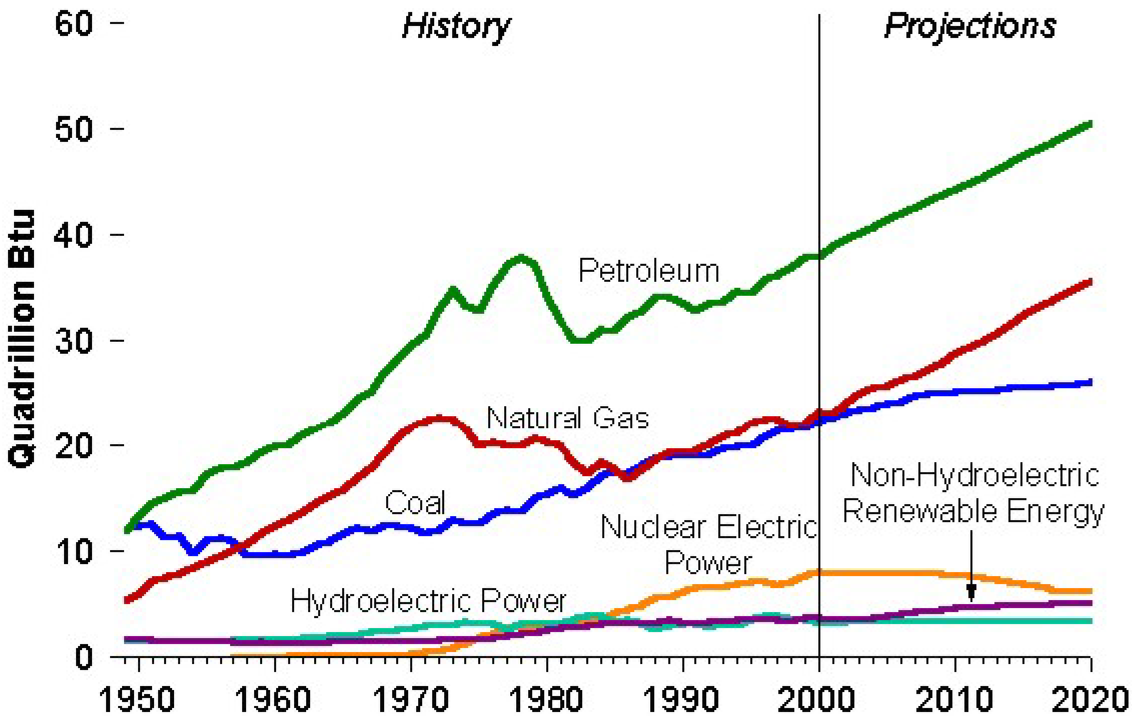
All sectors of the U.S. economy contribute to energy-related greenhouse gas emissions, especially CO_2. Of 1999 energy-related CO_2 emissions of 1.5 billion metric tons of carbon (5.6 billion tons of gas), the industrial and transportation sectors each accounted for about one-third, the residential sector for about one-fifth, and the commercial sector for the remainder. Industry's emissions derive from a broad mix of fossil-origin energy, including electricity, petroleum, natural gas, and coal. Not surprisingly, the transportation sector emits carbon dioxide mostly via the consumption of petroleum (especially motor gasoline, distillate fuels such as diesel, and jet fuel). Residential- and commercial-sector emissions are owed mostly to the use of electricity and natural gas.

The U.S. Energy Outlook as of 2001

Future patterns of energy production, use, and consequences in the United States are, of course, purely speculative. But educated guesses can be made by means of sophisticated computer models, such as the Energy Information Administration's National Energy Modeling System (NEMS). At this writing, EIA's current projections are published in its *Annual Energy Outlook 2001* (*AEO2001*) and extend through 2020. Although emphatically not to be taken as predictions--no model pretends to be able to foresee critical but unexpected events, such as the 1973 oil embargo--EIA's projections can sketch a plausible general picture of future developments.

The projections in *AEO2001*, which assume known trends in technology and demographics and current laws, regulations, and policies, suggest that our near-term energy future will be one of more: greater consumption, production, and imports, and higher emissions. Real energy prices are expected either to increase slowly (petroleum and natural gas) or to decline (coal and electricity). These circumstances will encourage greater consumption (Figure 33), and *AEO2001* projects U.S. total consumption to reach 127 quadrillion Btu in 2020, 29 percent higher than in 2000. Consumption rises in all sectors, but growth is especially strong in transportation because of more travel and greater freight requirements.

Figure 33. Energy Consumption History and Outlook, 1949-2020



Despite gains in energy efficiency, higher demand for energy services is expected to raise per-capita energy use slightly over the forecast period. Energy intensity, expressed as energy use per dollar of gross domestic product, has declined since 1970 and is expected to continue falling.

More energy consumption, of course, means more energy production--somewhere. Because the output of aging U.S. oil fields will continue to drop, rising demand for petroleum will have to be met by imports. The share of U.S. petroleum consumption met by net imports is projected to rise from 52 percent in 2000 to 64 percent in 2020. Domestic natural gas production increases 2.1 percent per year on average, but demand rises enough to require a significant boost in natural gas imports. Output from the Nation's vast coalfields likewise increases to meet rising domestic demand. Growth in production of energy from renewable sources is expected to average about 1.1 percent per year, while output from nuclear power facilities declines at the same rate.

Unless measures to reduce emissions of carbon dioxide are adopted, greater use of fossil fuels, slow market penetration by renewable energy sources, and less use of nuclear power will inevitably lead to higher emissions. *AEO2001* projects U.S. energy-related carbon dioxide emissions to exceed 2 billion metric tons of carbon (7.5 billion tons of gas) in 2020, 33 percent more than in 2000.

What of our long-term energy future? That is even more speculative. Many would argue that the world is destined to move beyond fossil fuels eventually; if the threat of global climate change does not compel it, then exhausted supplies and rising prices might. The far future seems likely to belong to renewable sources of energy. Although the form they take may be radically different than in the past--solar hydrogen and advanced photovoltaics, perhaps, rather than fuelwood and dung--humankind's sources of energy thus will have come full circle.

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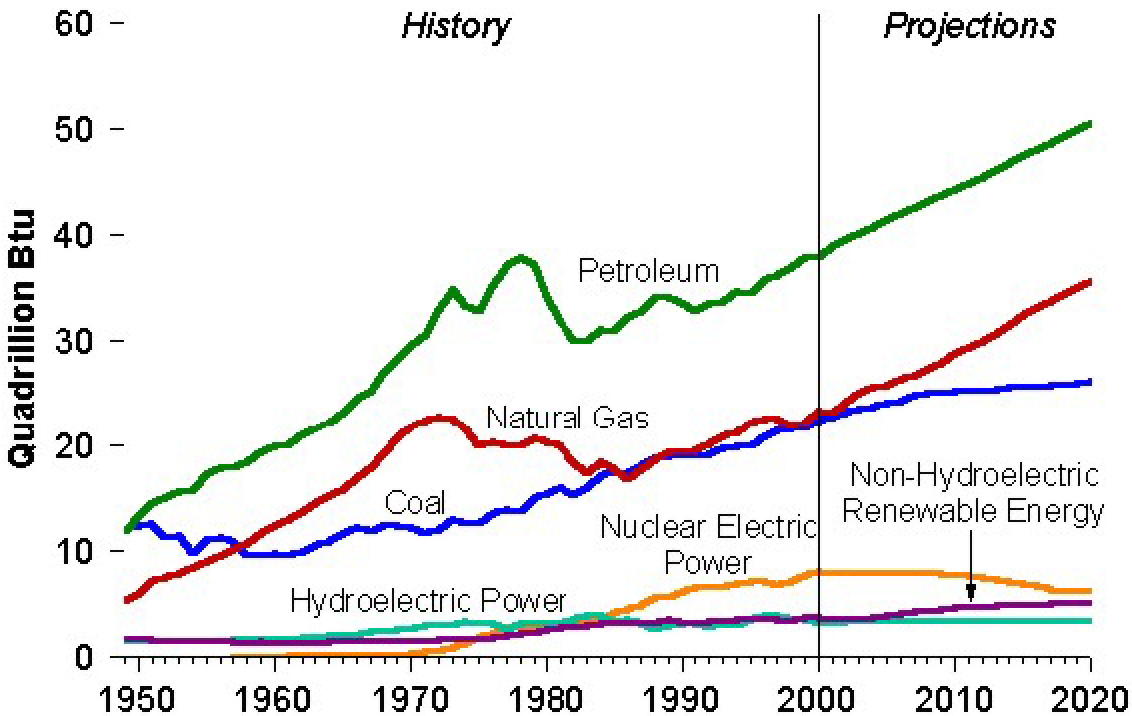

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More energy consumption, of course, means more energy production--somewhere. Because the output of aging U.S. oil fields will continue to drop, rising demand for petroleum will have to be met by imports. The share of U.S. petroleum consumption met by net imports is projected to rise from 52 percent in 2000 to 64 percent in 2020. Domestic natural gas production increases 2.1 percent per year on average, but demand rises enough to require a significant boost in natural gas imports. Output from the Nation's vast coalfields likewise increases to meet rising domestic demand. Growth in production of energy from renewable sources is expected to average about 1.1 percent per year, while output from nuclear power facilities declines at the same rate.

Unless measures to reduce emissions of carbon dioxide are adopted, greater use of fossil fuels, slow market penetration by renewable energy sources, and less use of nuclear power will inevitably lead to higher emissions. *AEO2001* projects U.S. energy-related carbon dioxide emissions to exceed 2 billion metric tons of carbon (7.5 billion tons of gas) in 2020, 33 percent more than in 2000.

What of our long-term energy future? That is even more speculative. Many would argue that the world is destined to move beyond fossil fuels eventually; if the threat of global climate change does not compel it, then exhausted supplies and rising prices might. The far future seems likely to belong to renewable sources of energy. Although the form they take may be radically different than in the past--solar hydrogen and advanced photovoltaics, perhaps, rather than fuelwood and dung--humankind's sources of energy thus will have come full circle.

Bibliography

Banks, F. The Political Economy of Natural Gas. London: Croom Helm, 1987.

Dukert, J. A Short Energy History of the United States. Washington, DC: Edison Electric Institute, 1980.

Energy Information Administration. *Annual Energy Outlook 2001*: With Projections to 2020. DOE/EIA-0383 (2001). Washington, DC: December 2000.

Gielecki, M. and Hewlett, J. "Commercial Nuclear Electric Power in the United States: Problems and Prospects." Energy Information Administration, Monthly Energy Review, August 1994, DOE/EIA-0035(94/08) (Washington, DC, August 1994).

Glasstone, S. Energy Deskbook. Washington, DC: U.S. Department of Energy, Technical Information Center, 1982.

Herbert, J. Clean Cheap Heat: The Development of Residential Markets for Natural Gas in the United States. New York: Praeger, 1992.

Hyman, L. America's Electric Utilities: Past, Present, and Future. Arlington, VA: Public Utilities Reports, 1983.

Lindbergh, K. and Provorse, B. Coal: A Contemporary Energy Story. Seattle: Scribe Publishing Corporation, 1977.

McCaig, R. Electric Power in America. New York: Putnam, 1970.

Schurr, S. and Netschert, B. Energy in the American Economy, 1850-1975: An Economic Study of Its History and Prospects. Baltimore: The Johns Hopkins Press, 1960.

Smil, V. Energy in World History. Boulder: Westview Press, 1994.

----. General Energetics: Energy in the Biosphere and Civilization. New York: John Wiley & Sons, 1991.

Tenner, E. Why Things Bite Back: Technology and the Revenge of Unintended Consequences. New York: Knopf, 1996.

Tussing, A. and Tippee, B. The Natural Gas Industry: Evolution, Structure, and Economics. Tulsa: PennWell Books, 1995.

United States Geological Survey, Mineral Resources of the United States. Washington, DC, 1883.

Walton, R. The Power of Oil. New York: Seabury Press, 1977.